Gap Creek Circuit Mountain Bike Trail: Long Term Environmental and Use Impacts

prepared for
Gap Creek Trails Alliance

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Executive Summary

This report is of a year-long study to monitor and assess *Gap Creek Circuit* mountain bike trail to look for significant changes under measured use and rainfall conditions. The study ran from April 2009 to April 2010.

Gap Creek Circuit is situated in Mt Coot-tha Forest, in Brisbane, Queensland. Mt Coot-tha Forest possesses grassed recreational areas, 31 km of shared-use trails and 18.5 km of walking trails that pass through a variety of types of vegetation. *Gap Creek Circuit* is part of a 12 km network of purpose-built, mountain bike only trails. *Gap Creek Circuit* has been designed and built in accordance with internationally-recognised trail construction guidelines. The trail was opened in August 2008. Since in general trails take about one year to bed in through use and weather, and since the study began in April of 2009, measurements of change could be more exaggerated than if the study were begun (say) six months later.

Gap Creek Circuit was selected because: (1) it was built to guidelines recognised internationally as producing the most sustainable trails; (2) a rider, once started would finish the trail and not take a detour (the entire trail would be subject to the same use); and (3) the trail was not to be subjected to maintenance work during the course of the study.

Trail tread transect profiles at 20 randomly-selected transect points were measured on five occasions over the year. The lengths of the inter-survey periods varied and were 42, 105, 138, and 85 days. Relevant topography parameters such as trail gradient and sideslope gradient at each point were measured.

Rainfall was 1,135 mm over the course of the study. The portion of total rain that fell in each of the four inter-survey periods is 22, 10, 26, and 42 per cent.

Trail use is about 31 passes per day (approximately 11,200 passes per annum). Daily use did not vary greatly over the counting year.

Changes to the trail at the transect points can be calculated from the changes in the measurements describing the transect profiles. Ten (50 per cent) of the twenty transect points did not exhibit any change to the profiles and five (25 per cent) showed minor, insignificant change (soil movement) over the course of the study. A further two showed noticeable change (both with soil loss) and the remaining three (fifteen per cent) exhibited significant change (all with soil loss).

To put "significant change (soil loss)" in perspective, at none of the transect points would the soil loss along a 1 cm wide strip across the trail tread overflow a common, garden trowel.

The three transect points that showed significant change are on steep sections of the trail. Two have shallow trail to fall line angles. This combination pushes the envelope of good practice with respect to the trail building guidelines. The used tread widths (where 95 per cent of riders travel) at two of these transect points marginally increased while the used tread width at the third point decreased.

One of the transect points that showed noticeable change is on a steep section of trail and has an acceptable trail to fall line angle so only slightly pushes the envelope of good practice. The second of the points that showed noticeable change is nearly on a corner and has quite a distance to the upslope grade reversal. The associated section of trail has a modest grade, and has characteristics that would enable riders to approach the corner with some speed and it is likely that some of the change is due to riding practices.

At no transect was there evidence of gouging, deep wheel ruts or channels caused by erosion.

Changes in used tread width were recorded concurrently with the transect profile measurements. The 20 used tread widths varied from 21 to 48 cm and the mean used tread width increased insignificantly from 30 to 31 cm over the year of the study. Overall, 45 per cent of the transect points showed no change in used tread width (ie the change was within ±15 per cent of the tread width of the baseline survey), 25 per cent narrowed noticeably and 30 per cent widened noticeably. None of the tread widths that changed did so outside the edge of the trail as built and hence none showed signs of tread creep.

In summary, the physical properties (transect profiles and used tread widths) of trails built to conform to the IMBA guidelines indicate that for the most part trails in Mt Coot-tha Forest can withstand the combination of about 31 passes per day and 1,135 mm of rain per annum for at least one year with little impact on the trail surface or the width of the used portion of the trail. While continual maintenance of trails is always required, maintenance is likely to be required more often in those parts of trails that deviate too far from the guidelines while trail sections built within the guidelines will consume much less of the trail maintenance budget.

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Glossary of Terms, Abbreviations and Acronyms

Term	Description
Fall line	The steepest gradient of a hillside. Is the likely line of flow of water down a slope.
Fall line bearing (°)	On the downside (downslope side), the fall line bearing is the direction water would flow away from the point that is on the transect and just outside the tread. On the upside (upslope side) the fall line bearing is measured from the point on the line of the transect and at the top of the backslope and looking up the steepest slope of the hillside. The points from where the fall line bearings are taken are usually very close to the reference pegs.
Fall line gradient (%)	The gradient along the upslope fall line bearing and measured to the point at the top of the backslope and on the transect line.
IMBA	International Mountain Bicycling Association. Based in the US, this body's mission is to protect, create, and enhance quality trail experiences for mountain bikers worldwide. IMBA also actively promotes responsible mountain biking, supports volunteer trailwork, assists land managers with trail management issues, and works to improve relations among trail user groups.
MTB	Mountain bike
MTBA	Mountain Bike Australia. The controlling body for the sporting aspects of mountain biking in Australia.
Reference pegs	Engineering set-out pegs placed in the ground and used as the markers from which to set up the transect profile measuring apparatus. The direct line between the Upside Reference Peg and the Downside Reference Peg forms the transect across which the cross-section or profile is measured.
Sideslope gradient	The gradient of the hillside perpendicular to the trail. Measured from the point at the top of the backslope and on the transect line.
Single-track	A trail that is wide enough for one rider only.
Trail angle	The angle of the trail at a transect point. The angle is referenced to magnetic north. Measured in both directions from the middle of the used tread at the transect: (a) looking back towards the nominated start of the trail and (b) looking forwards towards the end of the trail.
Trail gradient/incline	The slope of the trail at the transect point.
Trail to fall line angle	The angle between the trail and the upslope fall line. The ideal angle is 90 degrees.
Transect	The plan view line between the reference pegs at the transect point. The transect is intended to be perpendicular to the trail.
Transect point	Point on the trail at which the transect cross-section, gradients and relevant angles are measured.
Tread	That part of the trail built to be ridden. Also known as the full tread or bench.
Used tread	That part of the tread that is actually ridden.

Acknowledgements

The study was commissioned by Gap Creek Trails Alliance in 2009 and was proudly funded by the Queensland Government's Gambling Community Benefit Fund. Stuart Clement Solutions would like to thank many people for their interest in and helpful criticisms of this project. These people come from a diverse range of backgrounds from professional to volunteer and include members of some of the communities that use recreational trails (mountain bikers, walkers, and horse riders), government officials, private trail-building contractors and people whose professional or personal expertise and interests overlap with aspects of the data gathering and analysis techniques used in the production of this report. Thanks are also due to Brisbane City Council staff as the land managers of *Gap Creek Circuit*, Mt Coot-tha Forest. Their cooperation in enabling this study is greatly appreciated.

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1 Introduction

1.1 Impetus

Mountain biking has become more popular since about the mid-1980s after its beginnings in the early 1970s. Early mountain bike tracks often became established with little or no regard to principles of sustainability. Mountain Bike Australia (MTBA), the peak Australian body responsible for the competitive aspects of mountain biking, has for many years expended considerable resources encouraging the building of single-tracks to the “sustainability” guidelines generated by IMBA (the International Mountain Bicycling Association).

Sustainable trail design and construction is defined by the IMBA in *Managing Mountain Biking* (2007) as:

- Protecting the environment;
- Requiring little maintenance;
- Meeting the needs of users; and
- Minimizing conflict between user groups.

In particular, “requiring little maintenance” aims for trails with long-term resistance to erosion from natural forces, and wear through use.

Mountain Bike Australia has been active in promoting best practice through sponsoring IMBA trail design and construction workshops and through information dissemination to mountain biking members and clubs. Gap Creek Trails Alliance is one such MTBA club that embraces the philosophy of sustainable trail design and construction and with MTBA is particularly interested in building a picture of how cross-country single-tracks in all parts of Australia fare under the local conditions of use, soil type and rainfall.

Previous studies conducted in other parts of the world have been in essence a singular “spot” record of trail changes. This study of *Gap Creek Circuit* is over a period of twelve months and hence is the second reported longitudinal study of sustainable MTB trail design performed in Australia.

1.2 Location

This report is of the year-long study of the mountain bike trail called *Gap Creek Circuit* situated in Mt Coot-tha Forest, in Brisbane, Queensland. Mt Coot-tha Forest, managed by Brisbane City Council, is a large area of 1,500 hectares whose main entrance is about 6 km west of Brisbane’s Central Business District. The forest extends about 7 km further west. The Mt Coot-tha Management Plan (2003) states that “The majority of the forest is classified as Conservation Area under the Brisbane City Plan (2000) with smaller portions classified as Parkland and Community Use. The Strategic Plan within City Plan also identifies Mt Coot-tha Forest as part of the Green Space System, having biodiversity and natural scenic values.” Further, “Mt Coot-tha Forest consists of a wooded open forest within a predominantly urban landscape. The public perception of the Forest is that of a ‘natural area’. Nevertheless, the area is likely to have been subject to Indigenous land management activities for many thousands of years prior to European settlement and, since European settlement, has been subject to extensive timbergetting and other disturbances. The extent of timber-getting is evidenced by the small number of timber-producing trees now existing in the Forest that are of any significant age. It is possible Mt Coot-tha Forest has a number of 'natural' states and that its future character will be shaped by active management of the area.”

The forest possesses grassed recreational areas, 31 km of shared-use trails and 18.5 km of walking trails that pass through a variety of types of vegetation. *Gap Creek Circuit* is part of a 12 km network of purpose-built, mountain bike only trails that has been designed and built with the IMBA guidelines in mind. The presence of shared-use and single-use trails reflects the cognisance of the

Brisbane City Council of the need to effectively manage the variety of recreational activities permitted in the Forest and their location (and prohibition in sensitive areas) reflects the desire to preserve and even enhance the natural environment while giving the community as much opportunity to enjoy and appreciate the character and uniqueness of such an area so close to a major city centre.

1.3 Focus

The study looks at soil movement through displacement and erosion from *Gap Creek Circuit* by observing the changes to the cross-section profile of the trail at 20 transect points along the trail. Changes to the used tread width (ie where at least 95 per cent of riders travel) are also measured. The technique is to measure changes in the cross-section of the track (ie shape and area) at the transect points using a horizontal beam set up in the same position for each of the five quarterly measurements over the year.

2 Methodology

2.1 Introduction

The methodology is copied from that used in the study performed by Stuart Clement Solutions for Mountain Bike Australia over the period 2008-9. This study was of two mountain bike trails in South Australia. The report of the study (*Monitoring and Assessing the Long-term Environmental and Use Impacts on Selected Mountain Bike Trails in South Australia*) is available on request from Mountain Bike Australia.

Since the methodology is the same, the descriptions in this Section 2 are modified only slightly from those given in the SA trail study. Stuart Clement Solutions is grateful that MTBA are keen to see consistency of descriptions in reports of studies such as these so that readers will gain a deeper understanding of the methods and outcomes in relation to the sustainability of mountain bike trails in a variety of soil types and climates around Australia.

2.2 Trail Selection

Gap Creek Circuit was chosen because a rider, having begun to ride will complete the entire trail, and cannot take a diversion. The trail has only two entry/exit points. This will give as high a representation as possible that the use for each of the sampling points along the trail is the same.

Gap Creek Circuit was also chosen as it is a mountain bike only trail, designed and constructed to IMBA guidelines for sustainable trails.

2.3 Transect Points

The transect points are located equidistantly along the trail with the position of the first being randomly determined relative to the trailhead; thus all points are regarded as randomly positioned. The transect points are marked with reference pegs set into the ground and close to flush with the surface. The pegs can be covered to conceal them from riders and can be uncovered easily for survey purposes.

The pegs are labeled Upside Reference Peg (URP) and Downside Reference Peg (DRP). All transect points have a clear upside and downside.

The pegs serve two somewhat conflicting purposes: they must be unobtrusive so the riding pattern of trail users is unchanged; and they must be reasonably easy to locate for subsequent measurements. Most of the pegs have been relatively easy to find in each survey and to ensure they are located in all surveys, triangulation information was recorded during the initial placement of the pegs. This triangulation consisted of measuring distances from each peg to large, (relatively) static objects nearby (for example trees).

2.4 Observation Timing

The study consists of five sets of measurement surveys about three months apart over the year of the study. These were performed in April, June, and September 2009, and continued into 2010 with surveys in January and April.

2.5 Transect Profile

2.5.1 Measuring Method

A transect profile (cross-section of the trail) is found by measuring the vertical distance from a horizontal straight edge to the trail surface at several measuring points along the trail transect (Figure 1). The transect is the plan view line between two reference pegs: the upside reference peg (URP) and its downside counterpart (DRP) placed each side of the trail. The straight edge is mounted on tripods and positioned so that the edge of the beam from which the measurements are taken is directly above the holes drilled into the middle of the top surface of each of the reference pegs. Accuracy is achieved using plumb bobs dropped from the straight edge to the pegs (Figure 1). Similarly, the vertical distance from the straight edge to the trail surface is found by dropping a plumb bob to the trail surface. A flat, steel tape measure is clamped to the top of the beam, and positioned so that the horizontal distance of each measuring point from the upside reference peg is recorded. A view of the apparatus setup is shown in Figure 1.

Figure 1 Transect profile measurement setup

The extent of the measurement is governed by what is adjudged to be the used tread width. The used tread width is bounded by the Upside Tread Boundary (UTB) and the Downside Tread Boundary (DTB). The used tread is defined as that part of the full tread that is used by at least 95 per cent of riders. The UTB and DTB are adjudged in the first (baseline) survey. If, during a subsequent survey, the used tread width is adjudged to have changed, then the new used tread boundaries are labelled UTB with a dash mark and DTB with a dash and measurements are taken at these new boundaries.

The transect boundaries of the second profile extend to 20 cm either side of the used tread. The boundaries are designated the Upside Measuring Limit (UML) and the Downside Measuring Limit (DML). The distance between these boundaries is referred to as the measuring limit. The dashed notation is used when the boundaries are different to the first (baseline) survey UML and DML. Measurements are taken at all of the reference point distances. That is, the original UML, UTB, DTB, and DML as well as at those points that have changed (the dashed notation points).

The method for determining each measuring point along the transect follows that given in Marion and Olive (2006) called the “variable interval cross-sectional area method”. This is “an adaptation of the traditional fixed-interval method” and is preferred due to (a) its improved accuracy in determining the shape of the profile when compared with the fixed-interval method; and (b) where tread surfaces at the transect are smooth rather than grooved or rocky, the measurement time can be considerably reduced.

The variable interval cross-sectional area (CSA) method reduces the profile of the tread across the trail (ie the transect) to a series of connected straight lines between the points where the transect visibly changes its cross-section slope (the “micro-topography”) (see Figure 2). This method enables a more complete and accurate calculation of the cross-sectional area than measuring at points at regularly-spaced intervals (eg every 50 mm) across the transect though care must be taken to ensure that the subjectivity involved in the selection of the measuring points is reduced as much as possible.

Figure 2 shows a representation of a trail profile with the natural line of the hillside to the extreme left and right of the diagram. The horizontal straight edge is supported by tripods. The plumb bobs are shown over the reference pegs URP and DRP. The used tread width boundaries are indicated with UTB and DTB and the full measuring width boundaries 20 cm each side of the used tread width are indicated with UML and DML. Note that measurements are taken of the profile in this outer 20 cm part of the transect of interest.

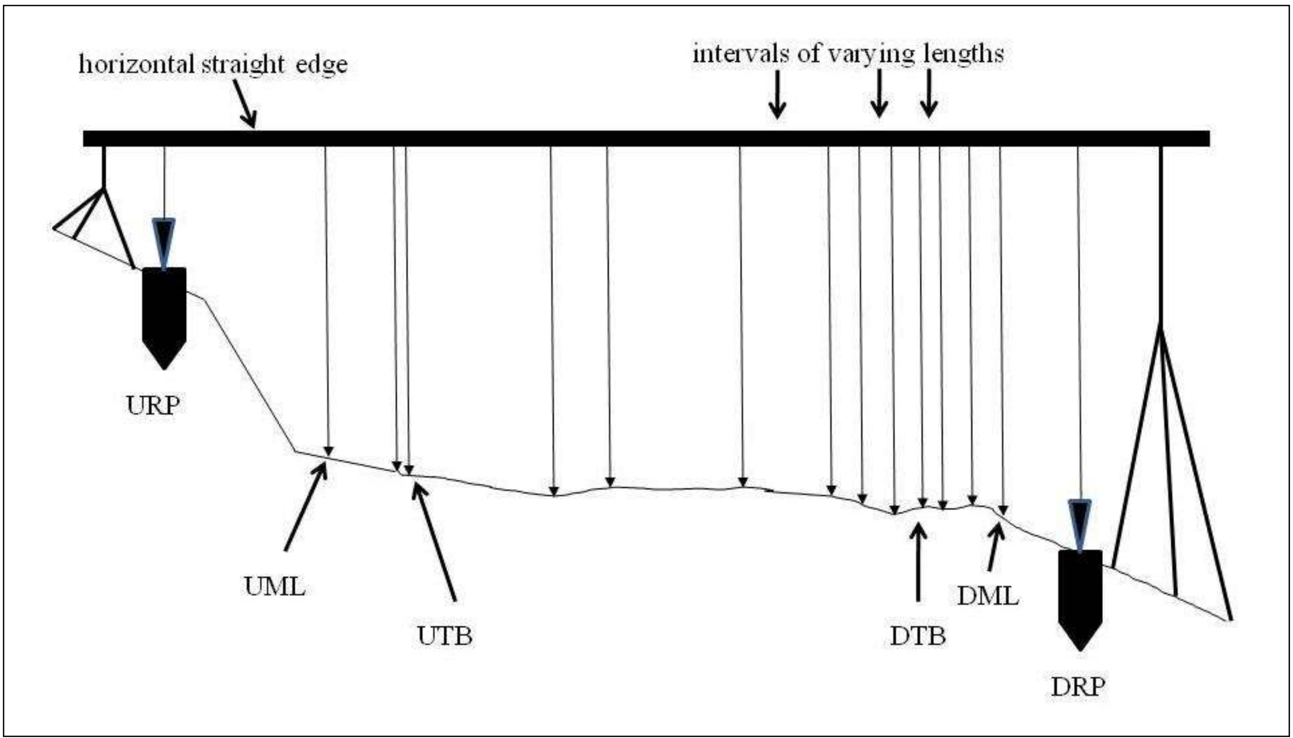

Figure 2 Diagram of the variable interval cross-sectional area method

2.5.2 Sources of Error

There are several sources of possible error associated with the method of using a horizontal straight-edge located directly over the reference pegs. The errors can occur in the following actions:

- the positioning of the straight edge by using plumb bobs over the reference pegs;
- the positioning of the measuring tape on the top of the straight edge relative to the upside reference peg;
- the judgement of 'level' by using a builder's level to set up the horizontal straight edge;
- the judgements involved in reducing the transect profile to a series of straight lines; and
- measuring errors for all vertical distances.

The accuracy can be affected by wind, the stability of the tripod holding the horizontal bar and of course the ability of the operator to adjudge the required position of the plumb bob with respect to the reference peg. A small hole (see Figure 1) drilled into the top of the reference peg improves the consistency of positioning. When taking the measurements and placing the tripods in particular, care is taken to disturb the vegetation and land forms as little as possible.

The compounding and confounding factor in performing the measurements for this study is that the measurements are performed more than once. While each of the above sources of error are present when performing a one-off study of a trail, the nature of performing five sets of measurements on each of the transect points of a trail means that the likely range of the error must be considered when drawing conclusions from the analysis of the measurements and subsequent calculations. For these reasons a small change in profile area between one survey and another may well be due to measurement errors and hence it is unwise to conclude that there has been either soil loss or gain for mean change in profile area values of less than 1.0 cm^2/cm. To be able to improve the accuracy would require a much more sophisticated (and more expensive) measuring technique capable of millimetre accuracy.

The most difficult vertical distance to measure was most often the Upside Reference Peg (URP) height. Due to the comparatively short distance between the top of the horizontal bar and the top of the peg, any errors in measurement constitute a higher percentage of the height than the same size error with respect to the Downside Reference Peg (DRP) height. It is the URP height that is used as the height reference for the graphs and the transect cross-section profile calculations. Any variation in this one measure or in the positioning of the measuring tape on the top of the straight edge for any one survey can be seen on the graph of the profiles as a vertical shift in the profile. Where this shift is apparent and the shape of the graphed profile is consistent with the graphs of the profiles from other surveys, it can be concluded that there has been insignificant change in the profile regardless of the mean change in cross-sectional area.

2.6 Transect Profile Cross-Section Area Calculation

The nature of the measuring technique (a horizontal bar supported on tripods) means that it is very difficult to set up the horizontal bar in the second to fifth surveys at the same height above the URP and the DRP as it was set in the first (baseline) survey. The survey analysis technique is designed so that adjusting the bar to exactly the same height is not a necessity as the height can be ‘standardised’ post-survey by a simple subtraction/addition process using a spreadsheet. That is, a height correction can be applied to the URP heights of surveys two to five to standardise their heights to that of the baseline survey. This technique also enables the profiles for a transect point to be graphed in a manner that allows height and shape comparisons.

Two profile cross-section areas are calculated for each transect point for each survey: the area bounded vertically by the used tread edges (ie the used tread profile bounded by UTB and DTB); and the area bounded a further 20 cm beyond the used tread edges (ie bounded by UML and DML).

If the used tread width boundaries relative to the reference pegs do not change from the baseline survey through all of the subsequent four surveys, the five cross-sectional areas can be calculated over the same portion of the transect.

In reality, the used tread width boundaries are rarely the same from one survey to the next due in part to changes in riding patterns and in part to changed judgements as to the location of the trail edges within which 95 per cent of riders travel. The used tread width may vary considerably: up to 30 per cent. Hence comparisons of the cross-sectional area over the used tread width portion of the transect from one survey to the next are likely to be invalid unless the area is calculated over the same portion of the transect.

The portion of the transect used for comparisons of the used tread width is that between the UTB and DTB of the baseline survey. Heights at these measurement positions for the four subsequent surveys are calculated using an interpolation method unless by some chance a measurement was taken at the baseline tread width (UTB and DTB) distances during a later survey.

Determining the measuring limit boundaries is slightly more complicated. Since on many occasions measurements in the four subsequent surveys were inadvertently not taken at least to the UML and DML of the baseline survey, the cross-sectional area for the measuring limit boundaries is measured over the widest portion of the transect common to all surveys.

Once the height of the bar is standardised and the profile reference points are found, the cross-sectional area of the profiles for each survey are calculated.

3 Analysis

The study seeks to find any significant changes between the cross-sectional areas at any of the 20 transect points over the course of the five surveys. The methods for doing this are:

- analysing changes in profile cross-sectional areas;
- graphing the profiles; and
- visual inspection aided by photographic record.

Combining these ensures the best interpretation of any differences to the trail at the transect points: one method is used to reinforce the other.

At each transect point two cross-section profile areas are calculated. The inner profile extends to the boundaries of the used tread width from UTB to DTB. The outer profile extends to the boundaries of the measuring limit from UML to DML.

The measure used for comparing cross-sectional areas is the mean change in profile area. This is calculated as the area between the two survey profiles being compared at the transect point (eg Survey #2 compared with Survey #1), divided by the distance over which the profiles are measured. The unit is given as square centimetres per centimetre (cm^2/cm). A positive mean change indicates the baseline profile (ie the profile from the first survey) as measured is below the compared profile from the later survey (ie this may indicate soil gain). As an example, if the difference in cross-sectional areas for the width of the used tread is calculated as 10 cm^2 and the width of the used tread (UTB to DTB) is 100 cm, then the mean change is 0.1 cm^2/cm.

An example of a graph of the transect profiles from a transect point that showed no discernible change over the study period is shown in Figure 3 (point GCC-4). The profile areas for all four subsequent surveys were calculated over the used tread width of the baseline survey. When compared with the baseline survey profile area, the results from later surveys give the mean change values of: 0.1, 0.6, -0.4 and 0.6 cm^2/cm. These apply to the profiles over the used tread width of the baseline survey. The corresponding measuring limit profile area mean change values are: -0.3, 0.3, -0.6 and 0.1 cm^2/cm. Even though on first inspection these figures suggest there was some change evident, these figures are typical of a transect point that has not shown discernible change.

As discussed in Section 2.5.2 there are occasions when the measurement errors compound to produce a mean change value that on first inspection may indicate significant change. This is where using the profile graphs, photographs, and visual inspection in conjunction is helpful in drawing conclusions about that particular transect point. That is, in drawing a conclusion of either:

- no change;
- minor, insignificant change;
- noticeable change; or
- significant change.

In general, a conclusion of "no change" is where the mean change is less than 1.0 cm^2/cm; "minor, insignificant change" is where the mean change is greater than or equal to 1.0 cm^2/cm but less than 2.0 cm^2/cm; "noticeable change" is where the mean change is greater than or equal to 2.0 cm^2/cm but less than 3.0 cm^2/cm; and "significant change" is where the mean change is greater than or equal to 3.0 cm^2/cm.

Where the graphs of each of the profiles have similar shape but may be vertically displaced by a small amount, it can be assumed that the measuring errors as discussed above have compounded to produce a larger mean change value than actually occurred.

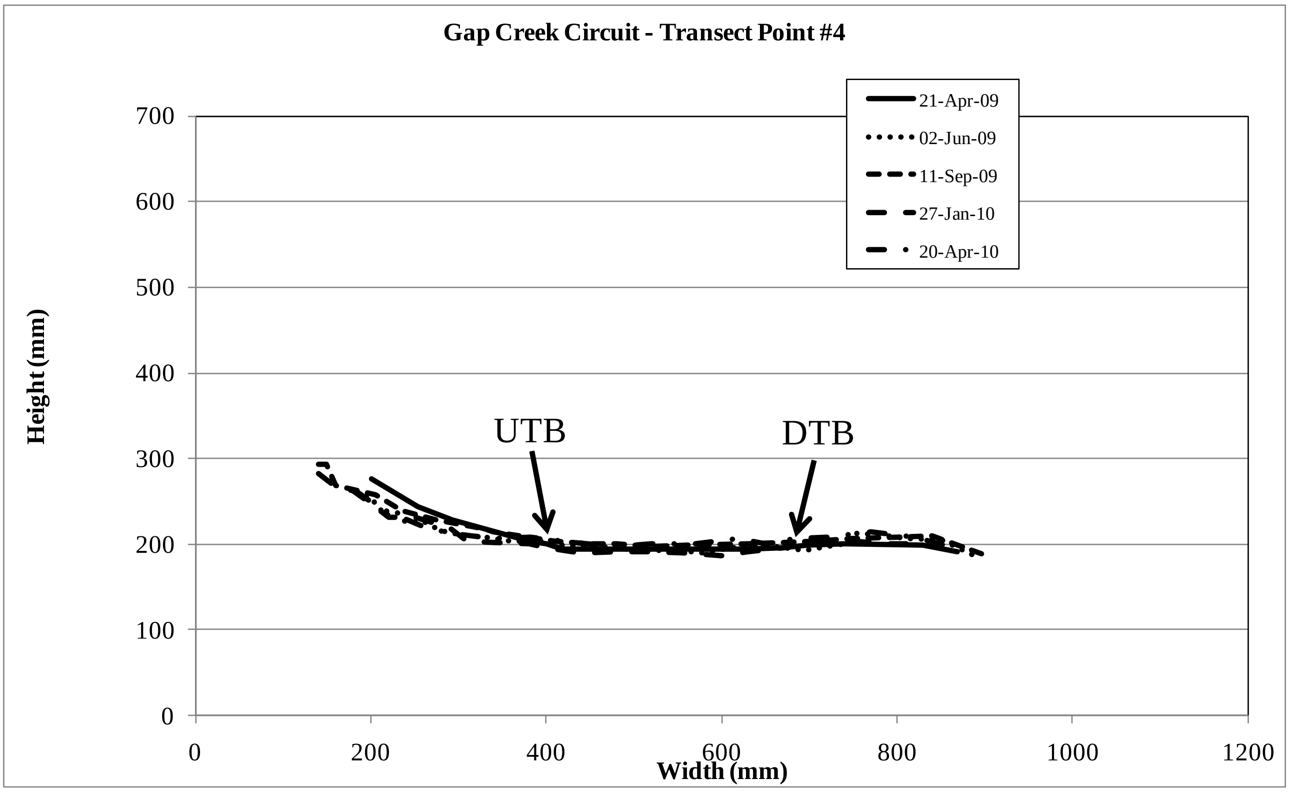

Figure 3 **Example profile graph of a transect point exhibiting no change in cross-sectional areas over the study period**

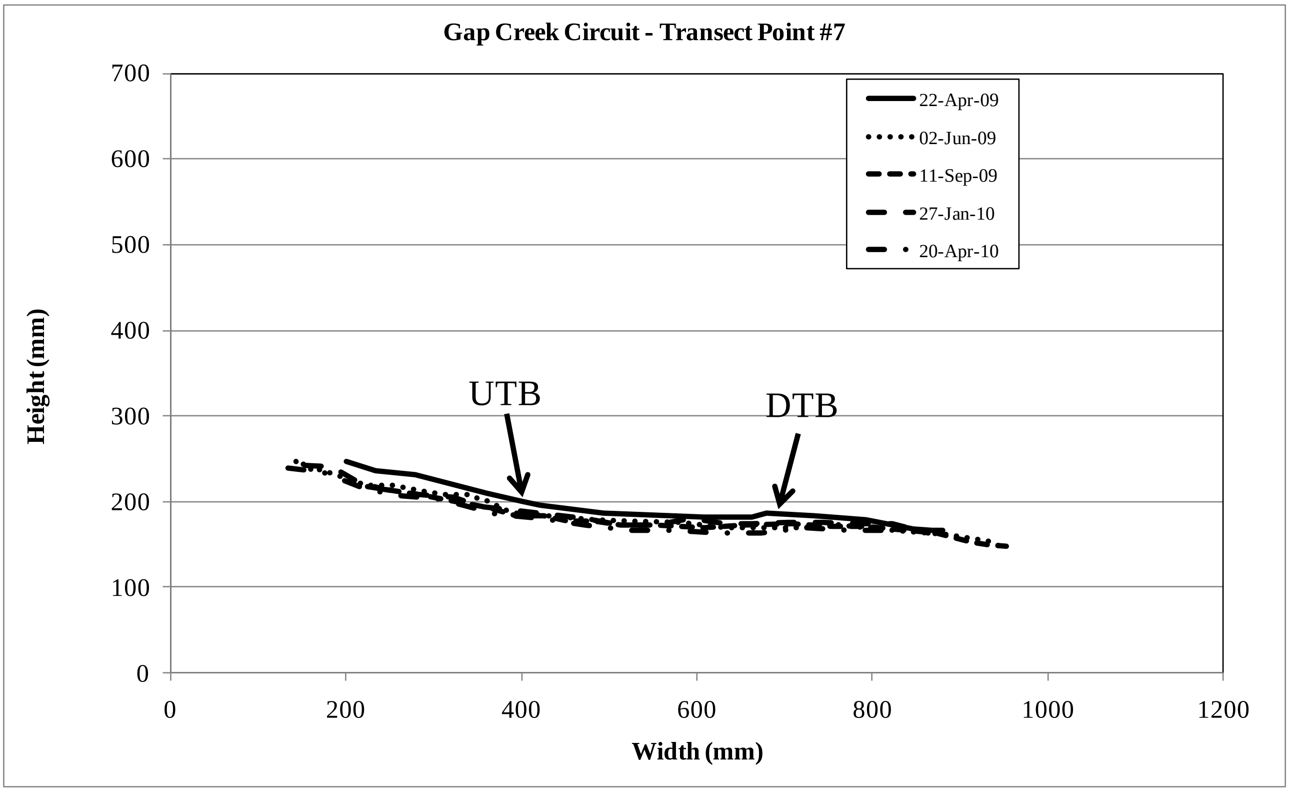

Figure 4 **Example of a consistent set of transect profiles**

An example of this vertical shift due to measurement error in the URP of the baseline survey given in Figure 4Figure 4 Example of a consistent set of transect profiles

where it could appear that the entire width of the trail is changing at a remarkably similar rate. This is unlikely to occur and is not the case here. The mean change in used tread width profile area values associated with transect point GCC-7 when Survey #1 is compared with the four later surveys are: -1.0, -1.2, -0.9 and -1.7 cm^2/cm respectively. If the measurement for the height of the URP is in error by 9 mm (or indeed if the value is written down incorrectly in the field or transcribed erroneously during processing of the data) in the first survey then the four compared values become 0.0, -0.3, 0.0, and -0.7 cm^2/cm and the subsequent graph is more akin to that of

Figure 3 Example profile graph of a transect point exhibiting no change in cross-sectional areas over the study period

describing transect point GCC-4 (ie the vertical displacement between each profile line on the graph is much smaller than in Figure 4). Hence where the profiles have very similar shape but are vertically displaced, the profiles are described as ‘consistent’.

Topography characteristics of a transect point (eg trail gradient, trail to fall line angle) can assist in understanding the nature of wear and erosion at the point. For example, a transect point with mean change values indicating significant change may be on a section of trail with a gentle gradient but topography characteristics of a concave cross-section and a distance of more than 10 m to the uphill grade reversal could help explain the change in profile. The relevant topography details are contained in *Appendix A: Transect Point Parameter Data*. See Section 8 for descriptions of these characteristics.

4 Rainfall

Daily rainfall data are taken from the publicly-available Bureau of Meteorology web site and aggregated where appropriate for each inter-survey period.

Each measurement survey took at least two, sometimes non-consecutive, days to perform (see *Appendix B: Survey Dates* for the days on which each transect point was surveyed). This resulted in slightly different rainfall data when viewed from an individual transect point perspective. For example, the number of days between the April and June 2009 surveys for GCC-1 was 42 days, for GCC-7 it was 41 days, and for GCC-10 it was 42 days. The corresponding rainfall for each of these three transect points was 249 mm for GCC-1, 253 mm for GCC-7, and 253 mm for GCC-10. Hence the mean rainfall per day was 5.9 mm for GCC-1, 6.1 mm for GCC-7, and 6.0 mm for GCC-10.

See *Appendix C: Rainfall Data* for the following precise data for each transect point:

- total rainfall per inter-survey period;
- total year rainfall;
- inter-survey days;
- total days;
- mean rainfall per day per inter-survey period; and
- mean rainfall per day per year.

The total rainfall over the year of the study period was 1,112 mm for transect points 1 to 10 and 1,135 mm for transect points 11 to 20. The difference is the 23 mm of rain that fell between the two days of the fifth survey in April 2010. Figure 5 shows the cumulative rainfall over the year of the study.

Table 1 contains the rainfall data for each inter-survey period. The data given here is a good representation of the precise data contained in *Appendix C: Rainfall Data*. For example, the rainfall per transect point that occurred between the January and April 2010 surveys was 457 mm for the first ten transect points and 480 mm for the others. The figure given in Table 1 splits the difference.

Table 1 Inter-survey rainfall

Inter-Survey Period	Days	Rainfall (mm)	Per Cent of Total	Mean Rainfall per Day
April – June 2009	42	249	22	6.0
June – September 2009	105	116	10	1.2
September – January 2010	138	289	26	2.1
January – April 2010	85	468	42	5.6

The most rainfall in a single day occurred on 17 February 2010 when 121 mm of rain fell.

The mean daily rainfall figures between each survey are shown in Figure 5. It should be noted that there was a significant rain event over the three days of 19 – 21 May 2009 when 221.8 mm of rain fell. This equated to nearly 17 per cent of the total fall for the study year and occasioned the trail to be closed for three weeks, re-opening on 12 June. The 26-day period between the end of Survey #1 and the first day of the rain event of 19 May saw 4.0 mm of rain fall. It can be assumed that use of the trail was normal during this period though the TRAFx mountain bike counters were not installed until 12 June. See Section 6 for the reasoning behind the trail use estimates for this period. The 21-day period from after the significant rain event up to Survey #2 (2 June) was unusually wet with a further 31.4 mm falling; hence the continued closure of the trail.

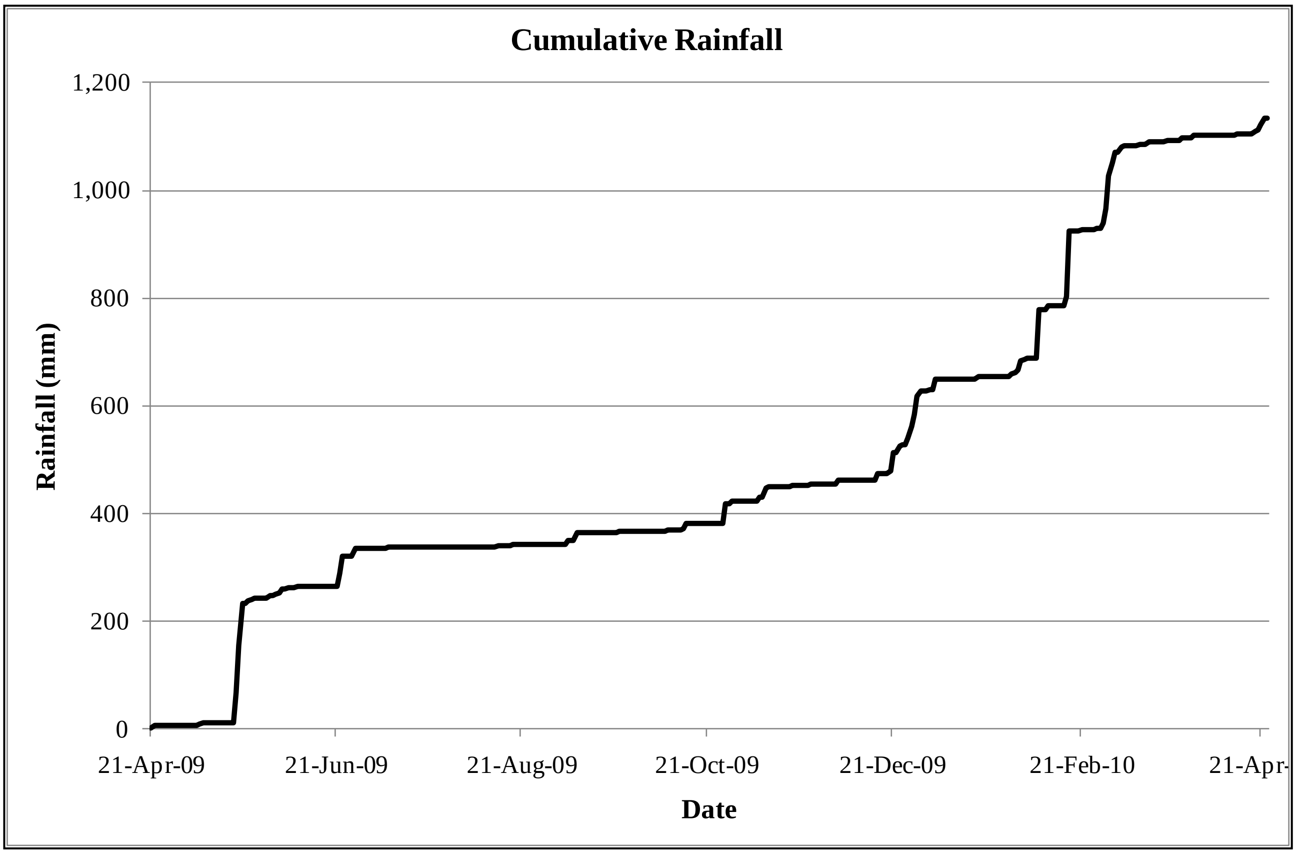

Figure 5 Cumulative rainfall over the study period

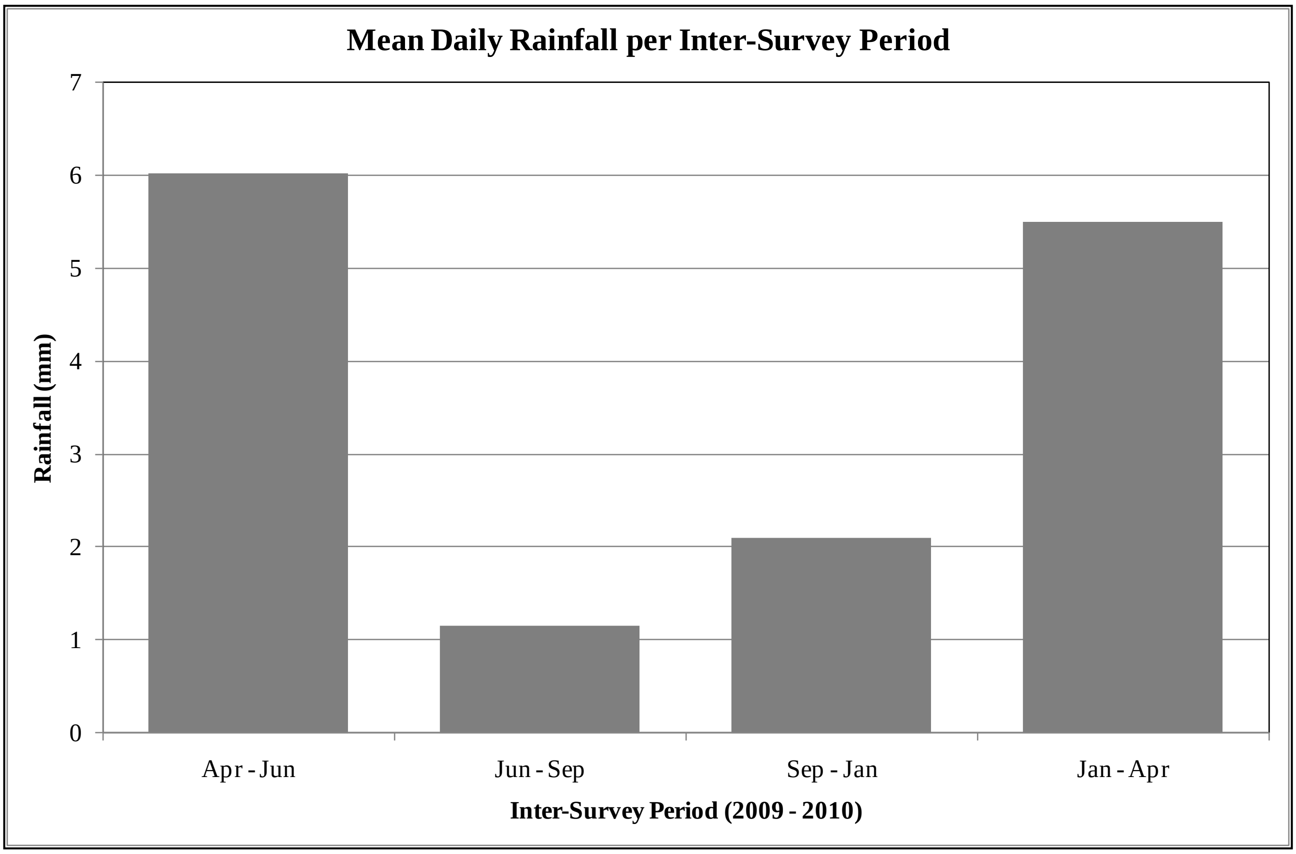

Figure 6 Mean daily rainfall over each inter-survey period

5 Soil Types

Rudimentary soil type determination was performed at each of the transect points. Determination was effected by placing some clean soil in a straight-sided jar, adding water, shaking thoroughly then allowing the jar to stand for at least five days. The relative amounts of sand, silt and clay are gathered from measurements of the height of each layer. The standard ribbon test was also performed.

The soil of *Gap Creek Circuit* is predominantly sandy loam. A moist ball of soil forms a ribbon less than 1 cm long and feels gritty.

The rudimentary method above revealed possible layering only at GCC-11. This appeared as about 60 per cent sand, with most of the rest silt with a small clay layer forming. Layering was at best indistinct in all the other transect point soil samples.

6 Trail Use

A fundamental part of this study is to count the use of the trail. TRAFx counters designed to record mountain bike traffic were purchased and initially deployed on 12 June 2009.

Two TRAFx counters were deployed on *Gap Creek Circuit*. One of the pair, GCC01, was deployed at the nominated start of the trail, with counter GCC02 deployed at the other end. Two counters are used in an effort to cross-check the counts and to provide redundancy. Mountain bikers using the trail are expected to pass both counters and all intervening transect points since there are no exit points on the trail.

The counters were not deployed until some time after the first set of transect profile measurements were performed on 21 and 22 April 2009. Part of the delay was the closure of the trial from 19 May due to a significant rain event (see Section 4). The trail was re-opened and the counters deployed on 12 June 2009. Data were retrieved regularly and due to the delay in initial deployment, data were continued to be retrieved through to 25 June 2010.

No calibration effort was performed on the counters during the study period so the figures recorded are the ones used. That is, corrective factors from calibration efforts as described in Clement (2010) are not applied to the figures recorded at *Gap Creek Circuit*.

The mean use of the trail is consistently between 29 and 34 passes per day from 12 June 2009 through to 23 April 2010 for GCC01 at the start of the trail and between 26 and 33 passes per day for GCC02 at the end of the trail. The mean use of the trail between 23 April and 25 June 2010 was 31 passes per day for GCC01 and 30 passes per day for GCC02. These figures are consistent with the rest of the counts over the study year and hence a reasonable working value for the number of passes per day on *Gap Creek Circuit* is 31 or a little less than 1,000 per month.

Excluding the days of the surveys themselves, there were 40 days between the first two surveys when riding was theoretically possible. The trail was closed to users for 14 days due to the significant rain event leaving 26 days when the trail could be ridden. Since the changes in use per day are minimal over the inter-survey periods during which counts were recorded, and assuming 31 passes per day were occurring when the trail was open, the total use is estimated at about 800 passes over the period from 23 April to 1 June 2009 inclusive.

Table 2 contains the details of the use of *Gap Creek Circuit* between the surveys of the study. The value used for the passes per day is the higher value recorded by the counters. In all cases the value used was from counter GCC01.

Table 2 Inter-survey trail use

Survey A	Survey B	Days	Passes Per Day	Passes	Per Cent of Total
1	2	26	31	800	7
2	3	92	34	3,200	29
3	4	138	32	4,500	40
4	5	85	31	2,700	24

7 Used Tread Width Changes

The used tread width is that part of the tread in which it is estimated that 95 per cent of riders will travel. Ascertaining the used tread width is in some cases a somewhat subjective exercise but for the most part, the travel line boundaries are reasonably clear to within a few centimetres across the transect. Part of the study is to see if the used tread widths change markedly over a twelve-month period and if they do, in what manner.

The used tread widths of the second survey of 2 June 2009 are discounted as the trail had been closed since 19 May and there was not a clear indication at most transect points of where riders had been riding before the closure. The most important comparison of used tread widths are those of the first and last surveys. The used tread widths of intermediate surveys are most useful in determining if there are trends in rider behaviour at a particular transect point (eg narrowing, widening, tread creep).

Of the twenty transect points on *Gap Creek Circuit* nine did not show marked change. That is, the change was within ±15 per cent of the tread width of the baseline survey. Five became narrower by 20 to 41 per cent. Four became wider by 22 to 38 per cent, one widened by 50 per cent and one by 73 per cent. None of the treads that changed did so outside the edge of the trail as built and hence none showed signs of tread creep.

The used tread widths varied from 21 to 48 cm and the mean used tread width increased insignificantly from 30 to 31 cm over the year of the study.

Overall, 45 per cent of the transect points showed no change in used tread width, 25 per cent narrowed noticeably and 30 per cent widened noticeably.

8 Transect Point Topographies and Characteristics

8.1 Elements

The elements of the topography of a transect point are the gradient (or incline), the bearing, and the proximity of the significant grade reversal. Both gradient and bearing apply to: (a) the trail itself; (b) the sideslope; and (c) the fall line. The significant grade reversal is that situated along the trail in the uphill direction.

The elements are described in the following sections along with explanations of how they are measured.

8.2 Trail Gradient

The trail gradients (inclines) are measured as you look away from the transect point in the indicated direction; ie from Start to End (from transect point #1 to transect point #20 aka ToEnd) or from End to Start (from point #20 to point #1 aka ToStart). A gradient is measured from the centre of the used tread to the point nearest the transect at which there is a discernible change in gradient. This point should be at most 10 m from the transect and in a direct line along the trail. Typically the change in gradient is between 2 and 5 metres from a transect point. If the transect point is on a bend then the distance to the change in gradient point may be quite short or could incorporate some of the bend. The gradient is measured from the centre of the used tread (where at least 95 per cent of riders travel) at the transect point to the centre of the used tread at the change in gradient. The point to which the gradient is measured could be at a decrease or an increase in gradient or a grade reversal. The important thing is that from the transect to the chosen point, there is a straight or nearly straight line along the trail. The gradient is measured in both directions. Measurement is given in the usual units of 'per cent'.

A positive trail gradient indicates that when looking along the trail from the transect point, the trail will rise. A negative trail gradient indicates a descent when leaving the transect.

8.3 Significant Grade Reversal

A grade reversal is where the slope of a trail levels out and changes the sign of its slope. There are thus two types:

(a) where a climbing trail levels out and then falls; and
(b) where a descending trail levels out and then begins to climb.

In terms of the sustainability of a trail, frequent grade reversals effectively divide the trail into small watersheds so that the gathering of water on any individual section does not affect another (Train, 2004) and also does not become too great causing undue erosion.

The grade reversal of interest to this study (ie the significant grade reversal) is that which is upslope (ie in the positive gradient direction) from the transect point. Note that this may often be further past the point to which the trail gradient is measured. This is recorded to give an indication of the length of trail that could conceivably catch water that may cause erosion of the trail. There is no need to record the distance to the trail downslope grade reversal.

8.4 Trail Bearing

The trail bearings (angles) are measured in degrees with respect to magnetic north and recorded from the transect to the measuring point where the trail gradient changes as this is a straight or nearly straight line along the trail. The trail bearing is measured in both directions. If the transect point is on a straight section of trail, the two bearings are expected to be 180º apart. If the transect point is on a bend, the bearing from Start to End and the bearing from End to Start will not be 180º apart.

8.5 Sideslope Gradient

The sideslopes are on a line through the reference pegs and hence are perpendicular to the trail. A sideslope gradient is measured on the sideslope line with reference to the point that is off the trail and is on ‘natural’ ground. That is, the reference point is as close to the trail as possible and on ground that has not been disturbed in the building of the trail. This point is likely to be close to the reference peg. Both the upslope and the downslope sideslopes are recorded and are measured from points on the appropriate sides of the trail. The upslope sideslope (upside) gradient will be positive as the gradient is recorded with the view referenced from the trail. The downslope sideslope (downside) gradient is therefore always negative.

8.6 Sideslope Bearing

The sideslope bearings (angles) are measured with respect to magnetic north and recorded in both directions looking from the middle of the trail along the sideslope line that passes through the reference pegs. The bearing for each of upslope and downslope is recorded as referenced from the trail and, within the tolerances of measurement error, should be 180º apart.

8.7 Fall Line Gradient

The fall line is the steepest slope with respect to the transect point. Like the sideslope gradient, the fall line gradient is recorded with reference to the point that is next to the trail, on the line of the transect and is on ‘natural’ ground. On the upside, the fall line is the steepest slope from the point next to the trail that is on natural ground. On the downside, the fall line is the steepest slope away from the point on the line of the transect next to the trail. The upslope fall line gradient will be positive. The fall line gradient has an absolute value that is at least equal to that of the sideslope gradient. The fall line of a contour trail often coincides with the sideslope.

8.8 Fall Line Bearing

The fall line bearings (angles) are measured with respect to magnetic north and recorded from the same point just off the trail as for the sideslope and fall line gradients.

8.9 Trail to Fall Line Angle

The trail to fall line angle is measured between the bearing of the trail where you climb away from the transect point and the fall line bearing. The value of the trail to fall line angle can give an indication of the potential susceptibility of that part of the trail to erosion from water runoff. Ideally water should spend as little time on the tread of the trail as possible and hence the optimum trail to fall line angle is 90 degrees with the tread constructed with out-slope.

9 Transect Point Analysis

The full list of parameter values for each transect point can be found in *Appendix A: Transect Point Parameter Data*. These parameters include the topography data and the measuring point distances.

9.1 GCC-1

This transect point is at a grade change at the start of a left-hand corner in a descending portion of trail. The trail for a few metres from the transect point to the grade reversal (10 m away in the ToStart trail direction) is slightly concave. This concavity continues at the transect point (see Figure 7 and Figure 8) and from the transect point in the ToEnd trail direction to the grade reversal about 10 m away. The distance to the upslope grade reversal is greater than 10 m.

Table 3 GCC-1 pertinent parameter values

Parameter	Value	Direction
Trail upslope gradient (%)	8	ToStart
Trail to fall line angle (°)	70	
Used tread width change (%)	38	

Table 4 GCC-1 mean changes in profile area for the used tread and the measuring limit

		Mean Change (cm^2/cm)	
Survey A	**Survey B**	**Tread**	**ML**
1	2	-0.3	-0.2
1	3	-1.3	-1.2
1	4	-2.3	-2.0
1	5	-3.1	-3.0

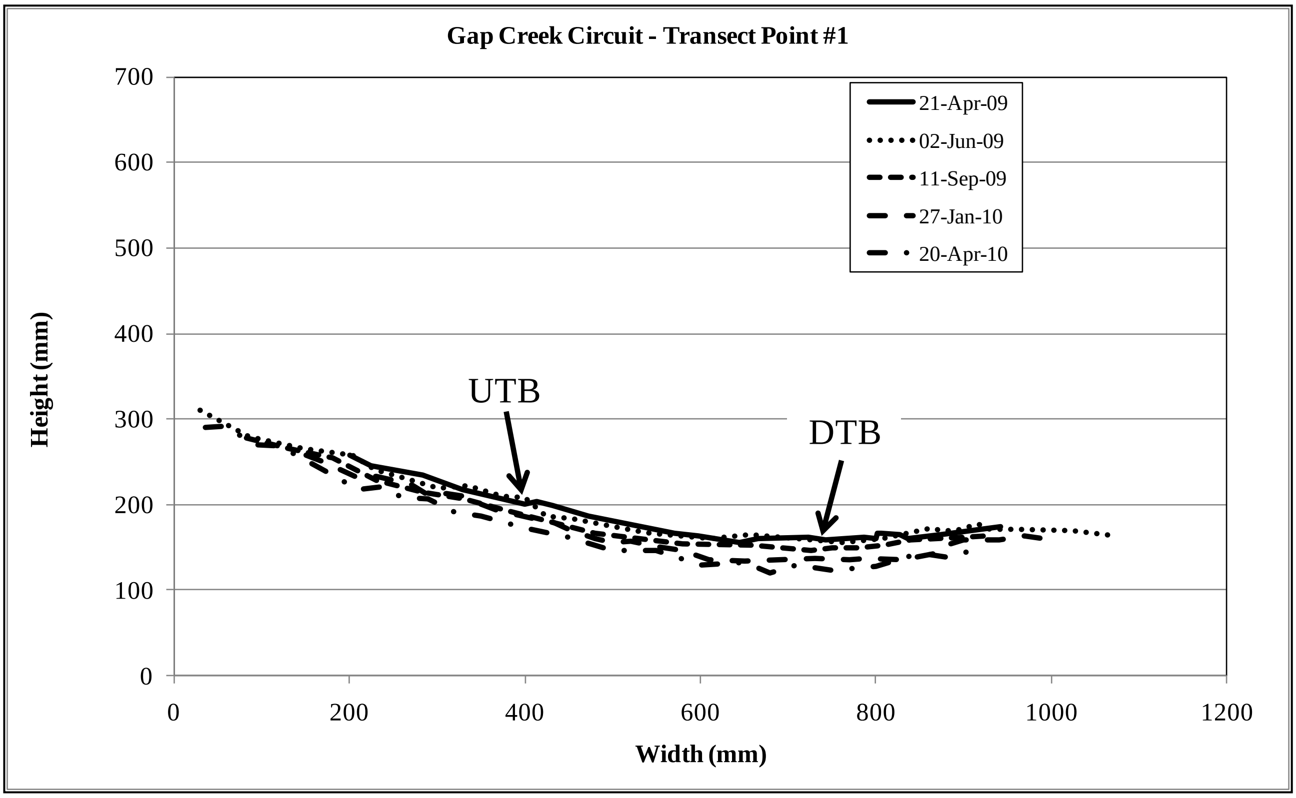

Figure 7 GCC-1 transect profile (URP as reference)

The bearings of the positive trail gradient and the upslope fall line result in an acceptable trail to fall line angle of 70 degrees: the ideal trail to fall line angle is 90 degrees. The tread surface is earth with many small (up to 1 cm across), loose stones interspersed with some slightly larger stones. The used tread width increased from 34 to 48 cm (an increase of 38 per cent) over the course of the study though this was still within the edges of the trail as built. There is no evidence of gouging at the transect point.

The values of mean change in profile area given in Table 4 show that there was consistent change occurring at this transect point over the course of the study. The differences in values show that there was no significant change between the first two surveys (April to June 2009) but consistent change (loss of soil) from the second through to the fifth survey. The profiles are shown graphically in Figure 7.

Figure 8 GCC-1 in April 2009 and April 2010

Conclusion: noticeable change (soil loss).

9.2 GCC-2

This transect point is at a drainage point and hence the trail rises away from the transect point in both directions (at gradients of 6 and 9 per cent towards the end of the trail and towards the start of the trail respectively) resulting in two values of trail to fall line angle (110 and 50 degrees respectively). The trail profile at this transect point is slightly concave. The tread surface is of packed earth with many small, loose stones interspersed with a few larger stones and possessing some vegetation litter. The values for the mean changes in profile area are within the range expected by the accuracy of the measuring method used in this study. The graph of Figure 9 shows the measured profiles from each survey overlapping. There is no evidence of gouging at this transect point. The values, the graph and the photographs indicate there has been no change to the trail surface profile at this transect point over the course of the study.

Table 5 GCC-2 pertinent parameter values

Parameter	Value	Direction
Trail upslope gradient (%)	6 & 9	To End & ToStart
Trail to fall line angle (°)	110 & 50	
Used tread width change (%)	-20	

Table 6 GCC-2 mean changes in profile area for the used tread and the measuring limit

		Mean Change (cm^2/cm)	
Survey A	**Survey B**	**Tread**	**ML**
1	2	-0.6	-0.2
1	3	-0.7	-0.4
1	4	-0.6	-0.4
1	5	-0.9	-0.7

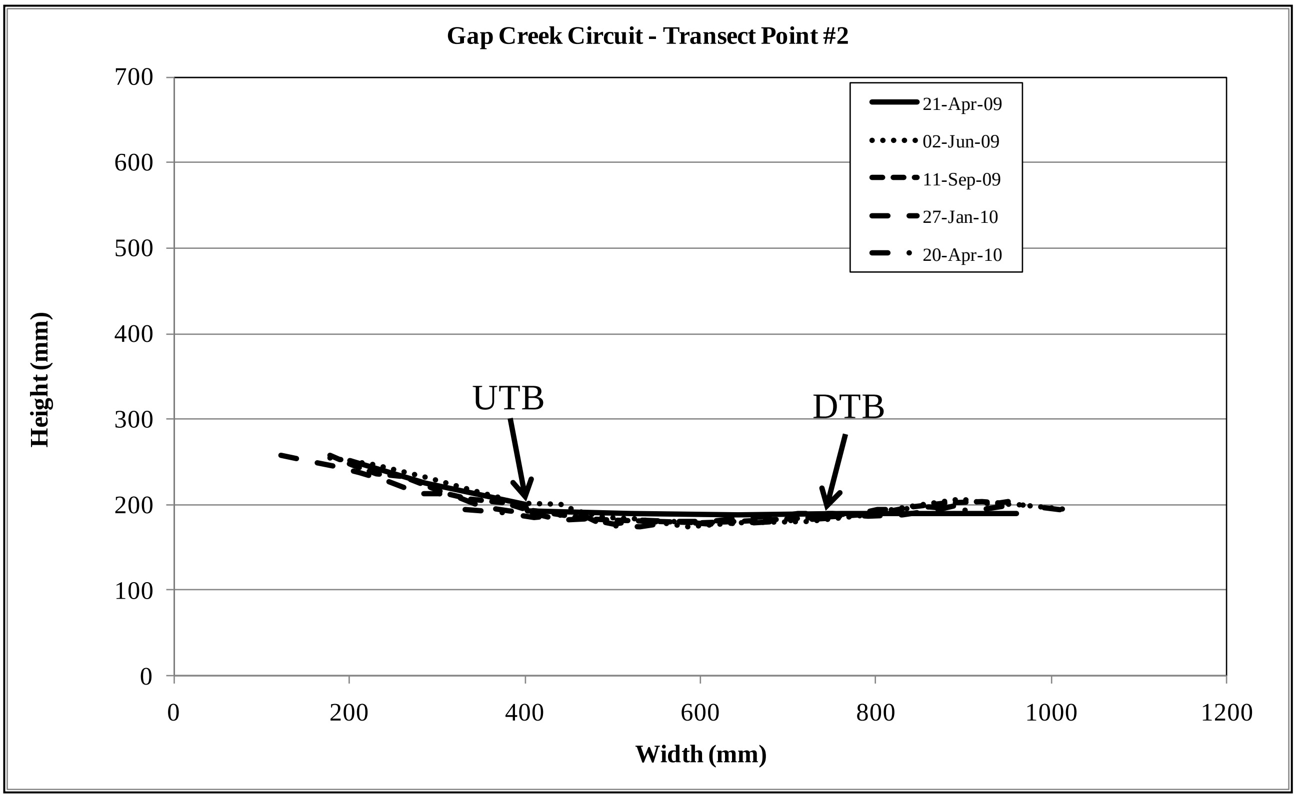

Figure 9 GCC-2 transect profile

The trail to fall line angle is 50°. This is much lower than the desired 90° but has not contributed to excessive change to the trail.

The used tread width reduced for the third and fourth surveys and was 20 per cent narrower than the baseline survey width by the time of the fifth survey.

Conclusion: no change

9.3 GCC-3

The surface of this transect point is of compacted earth with some fist-sized embedded stones and the usual small, loose stones and leaf litter.

The mean change in profile area values indicate soil loss occurred between the third (September 2009) and fourth (January 2010) surveys. Compared with the baseline profile area, the fourth survey profile results in a mean change of -2.2 cm^2/cm in profile area with a further much smaller soil loss occurring before the fifth (April 2010) survey. Closer inspection reveals that an embedded stone on the transect line was dislodged resulting in the inconsistent shape of the graphed profiles. There is no evidence of deep gouging occurring at this transect point.

The used tread width became narrower by 41 per cent over the course of the study with riders choosing a line closer to the downside of the trail though the downslope tread boundary did not alter significantly. It is towards this downside where the profile has altered.

The tread profile is concave. The upslope trail gradient is a reasonably steep 16 per cent with the grade reversal more than ten metres up the slope of the trail. Despite the steepness of the trail itself, the trail to fall line angle is 75 degrees.

Table 7 GCC-3 pertinent parameter values

Parameter	Value	Direction
Trail upslope gradient (%)	16	ToStart
Trail to fall line angle (°)	75	
Used tread width change (%)	-41	

Table 8 GCC-3 mean changes in profile area for the used tread and the measuring limit

		Mean Change (cm^2/cm)	
Survey A	Survey B	Tread	ML
1	2	-0.8	-1.0
1	3	-0.6	-0.5
1	4	-2.2	-2.1
1	5	-3.1	-2.7

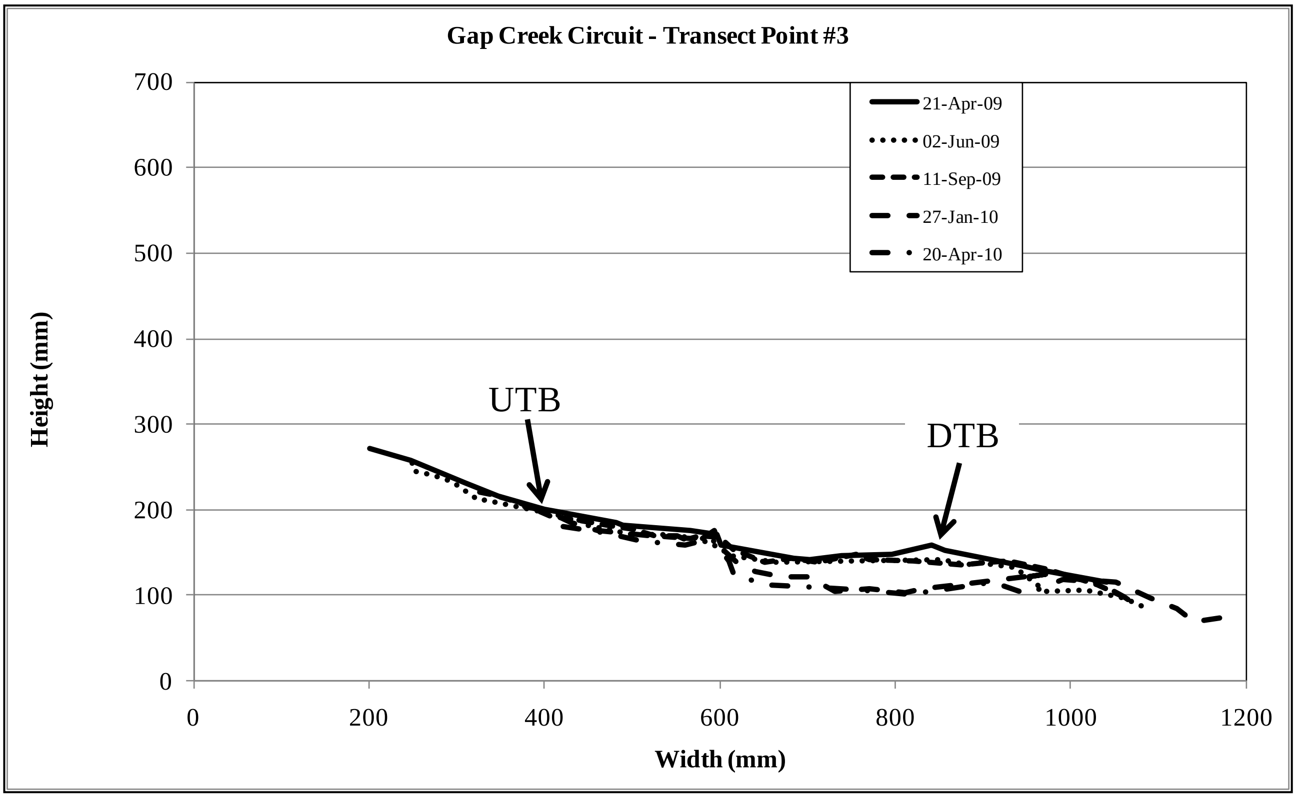

Figure 10 GCC-3 transect profile

Conclusion: noticeable change (soil loss).

9.4 GCC-4

There is no evidence of change occurring at this transect point which is on a rising section of trail at 3 per cent moving end-wards. The trail profile is slightly concave with a surface of packed earth, small, loose stones and leaf litter. The used tread width has increased by 13 per cent. The values of mean change in profile area are within the measuring limits of the study method and hence indicate no change in transect profile.

Table 9 GCC-4 pertinent parameter values

Parameter	Value	Direction
Trail upslope gradient (%)	3	ToEnd
Trail to fall line angle (°)	80	
Used tread width change (%)	13	

Table 10 GCC-4 mean changes in profile area for the used tread and the measuring limit

		Mean Change (cm^2/cm)	
Survey A	**Survey B**	**Tread**	**ML**
1	2	0.1	-0.3
1	3	0.6	0.3
1	4	-0.4	-0.6
1	5	0.6	0.1

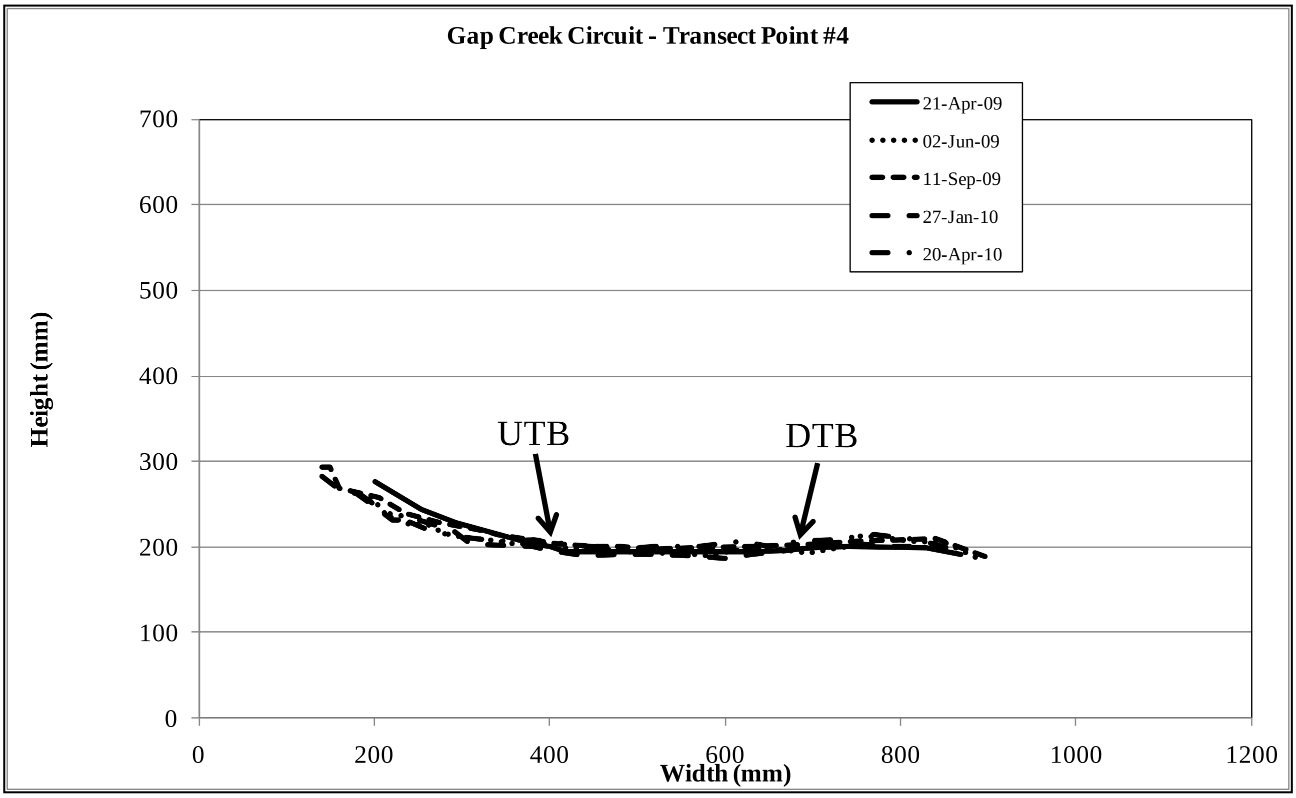

Figure 11 GCC-4 transect profile

Conclusion: no change.

9.5 GCC-5

The values of mean change in profile area indicate no change occurred at this transect point that has a shallow gradient and nearly flat transect profile. The used tread width has decreased by 26 per cent from 36 to 27 cm.

Table 11 GCC-5 pertinent parameter values

Parameter	Value	Direction
Trail upslope gradient (%)	2	ToEnd
Trail to fall line angle (°)	80	
Used tread width change (%)	-26	

Table 12 GCC-5 mean changes in profile area for the used tread and the measuring limit

		Mean Change (cm^2/cm)	
Survey A	**Survey B**	**Tread**	**ML**
1	2	0.0	-0.2
1	3	-0.2	-0.4
1	4	-0.2	-0.3
1	5	0.2	0.1

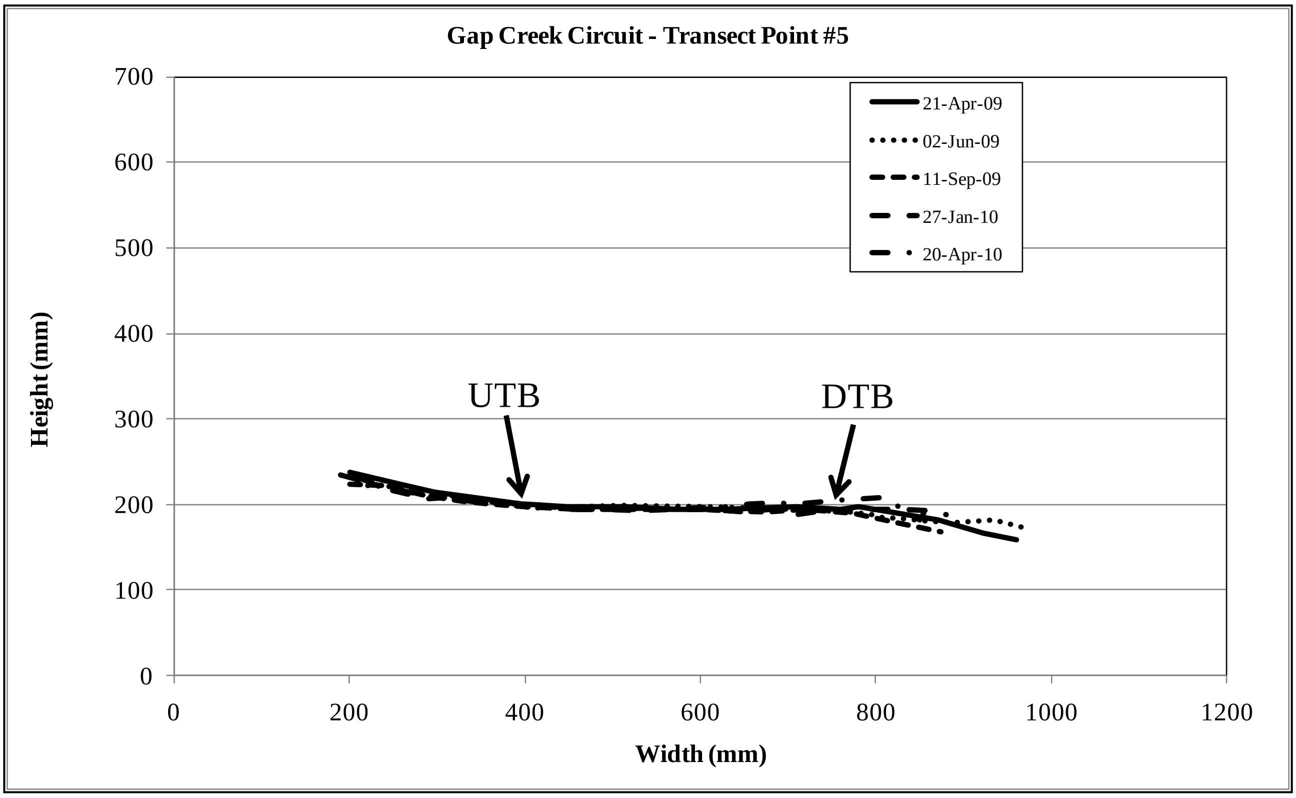

Figure 12 GCC-5 transect profile

Conclusion: no change.

9.6 GCC-6

The surface at this transect is of packed earth with some embedded stones, some small, loose stones and leaf litter. The tread is nearly flat with slight outslope. The gradient through the point is rising at 6 per cent when moving to the start of the trail.

Table 13 GCC-6 pertinent parameter values

Parameter	Value	Direction
Trail upslope gradient (%)	6	ToStart
Trail to fall line angle (°)	85	
Used tread width change (%)	-21	

Table 14 GCC-6 mean changes in profile area for the used tread and the measuring limit

		Mean Change (cm^2/cm)	
Survey A	Survey B	Tread	ML
1	2	0.0	-0.1
1	3	-0.1	-0.3
1	4	-0.3	-0.5
1	5	-1.5	-1.6

The values of mean change in profile area suggest a loss of soil between the fourth and fifth surveys. However, the profiles shown in Figure 13 indicate that this possible soil loss would have occurred in a consistent fashion across the entire measuring limit of the transect: highly unlikely. A more plausible explanation for the graph of the April 2010 profile being displaced from the others is that the figure for the URP height was written down incorrectly. The recorded figure of 251 mm gives mean change in profile area values of -1.5 and -1.6 cm^2/cm over the used tread width and measuring limit respectively. Changing the URP height of the April 2010 survey to 261 mm gives values of -0.5 and -0.6 cm^2/cm which are easily within measuring error limits. This change also results in the April 2010 profile being closely aligned with the others as expected. The graph shown in Figure 13 is with the data as recorded (ie URP height = 251 mm).

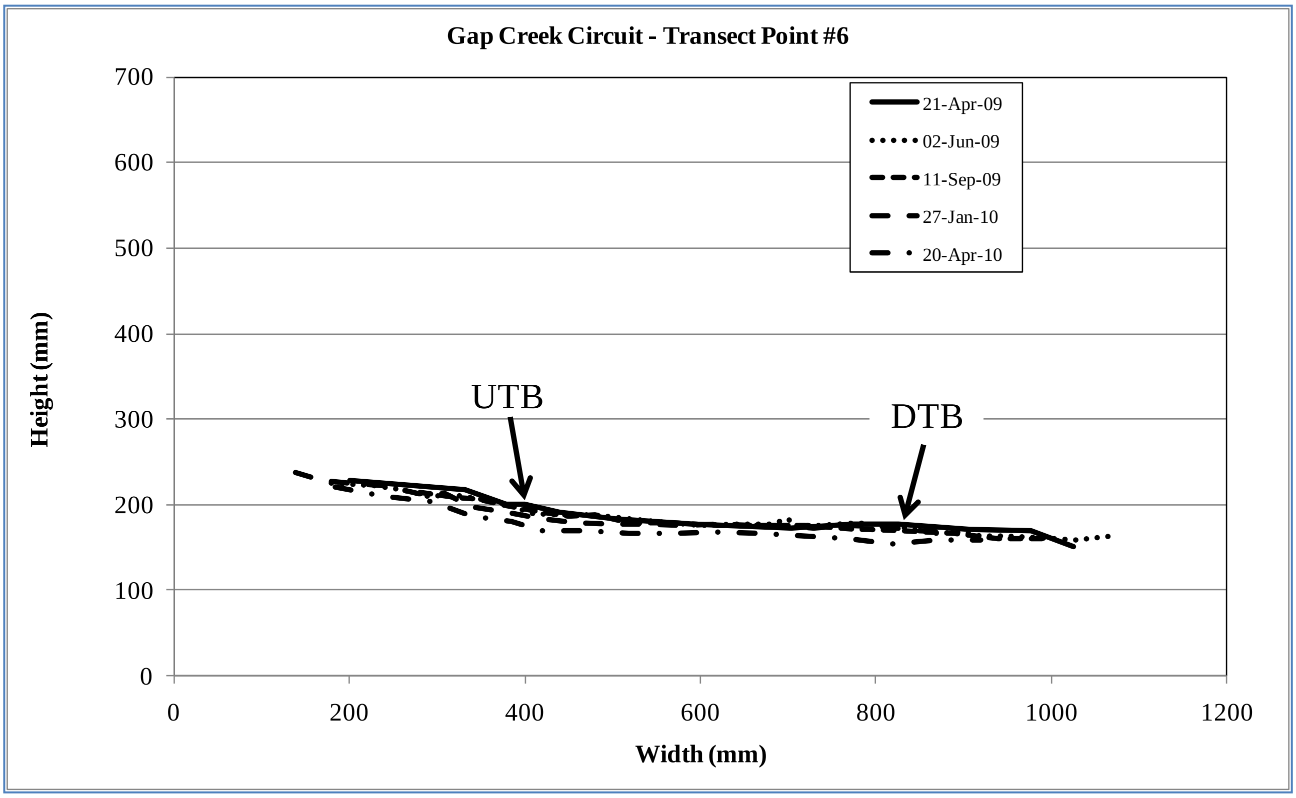

Figure 13 GCC-6 transect profile

Conclusion: no change.

9.7 GCC-7

Transect point GCC-7 is at the drainage point of a grade reversal. The surface is of packed earth with some small, loose stones and leaf litter. The used tread width has effectively not changed over the course of the study.

Table 15 GCC-7 pertinent parameter values

Parameter	Value	Direction
Trail upslope gradient (%)	6 & 6	To End & ToStart
Trail to fall line angle (°)	112 & 68	
Used tread width change (%)	4	

Table 16 GCC-7 mean changes in profile area for the used tread and the measuring limit

		Mean Change (cm^2/cm)	
Survey A	Survey B	Tread	ML
1	2	-1.0	-1.1
1	3	-1.2	-1.4
1	4	-0.9	-1.1
1	5	-1.7	-1.8

The profiles from all five surveys have a consistent shape across the entire measuring limit (see Figure 14) with the profiles from surveys two through five aligned well. Changing the measured height of the URP of the baseline survey from 431 to 421 mm generates a graph with all five profiles aligned and minimal values of mean change in profile area (see Table 17).

Table 17 GCC-7 mean changes in profile area for the used tread and the measuring limit with URP height changed from 431 to 421 mm

		Mean Change (cm^2/cm)	
Survey A	**Survey B**	**Tread**	**ML**
1	2	0.0	-0.1
1	3	-0.2	-0.4
1	4	0.1	-0.1
1	5	-0.7	-0.8

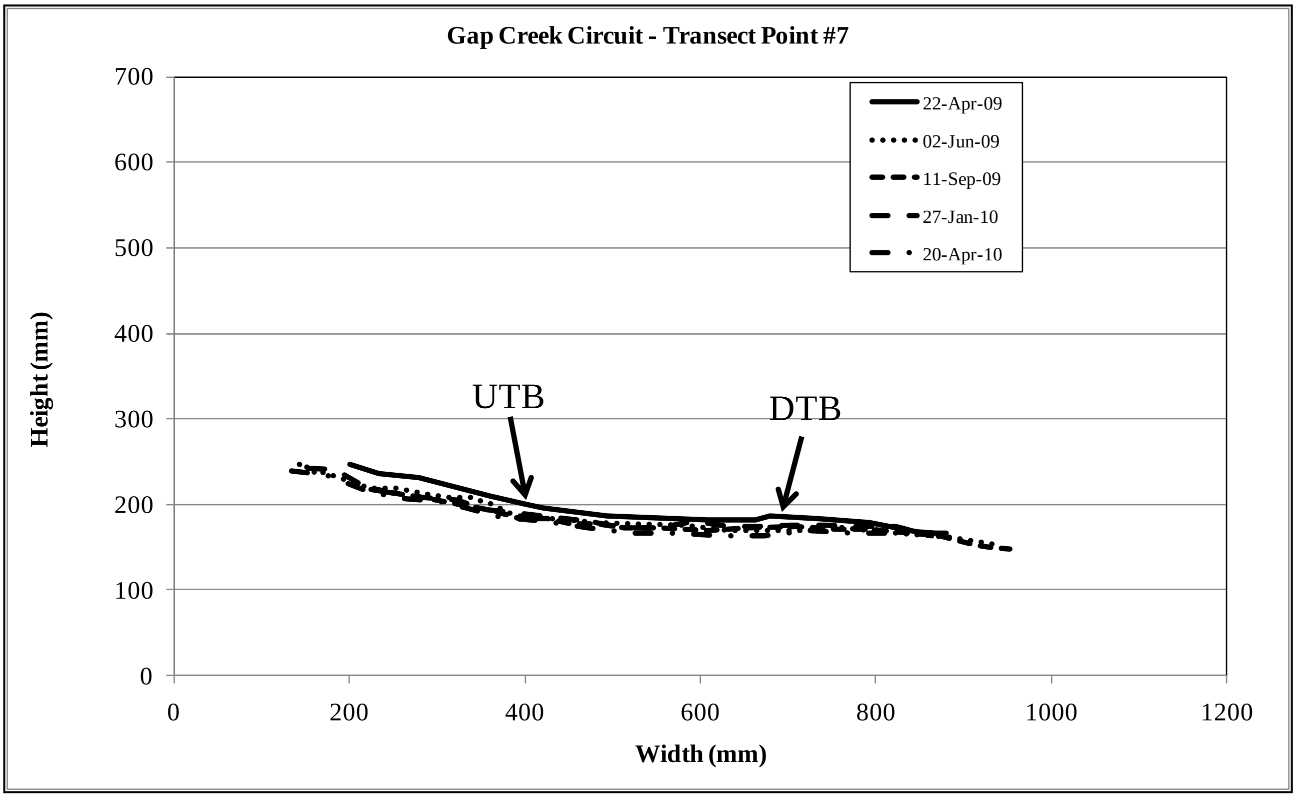

Figure 14 GCC-7 transect profile

Conclusion: no change.

9.8 GCC-8

This transect point is on a short, steep (22 per cent), ascending section of trail with the upslope grade reversal about 9 m away. The trail to fall line angle is 55 degrees. The tread surface is mainly small, loose stones with some larger stones (up to 40 mm across) present. As with the entire *Gap Creek Circuit* there is leaf and vegetation litter (usually comprising remnants of small twigs) present on the trail. The tread cross-section is concave and the used tread width decreased by 9 per cent over the course of the study.

Table 18 GCC-8 pertinent parameter values

Parameter	Value	Direction
Trail upslope gradient (%)	22	ToEnd
Trail to fall line angle (°)	55	
Used tread width change (%)	-9	

Table 19 GCC-8 mean changes in profile area for the used tread and the measuring limit

		Mean Change (cm^2/cm)	
Survey A	**Survey B**	**Tread**	**ML**
1	2	0.0	0.3
1	3	-1.3	-0.9
1	4	-1.8	-1.5
1	5	-2.2	-1.8

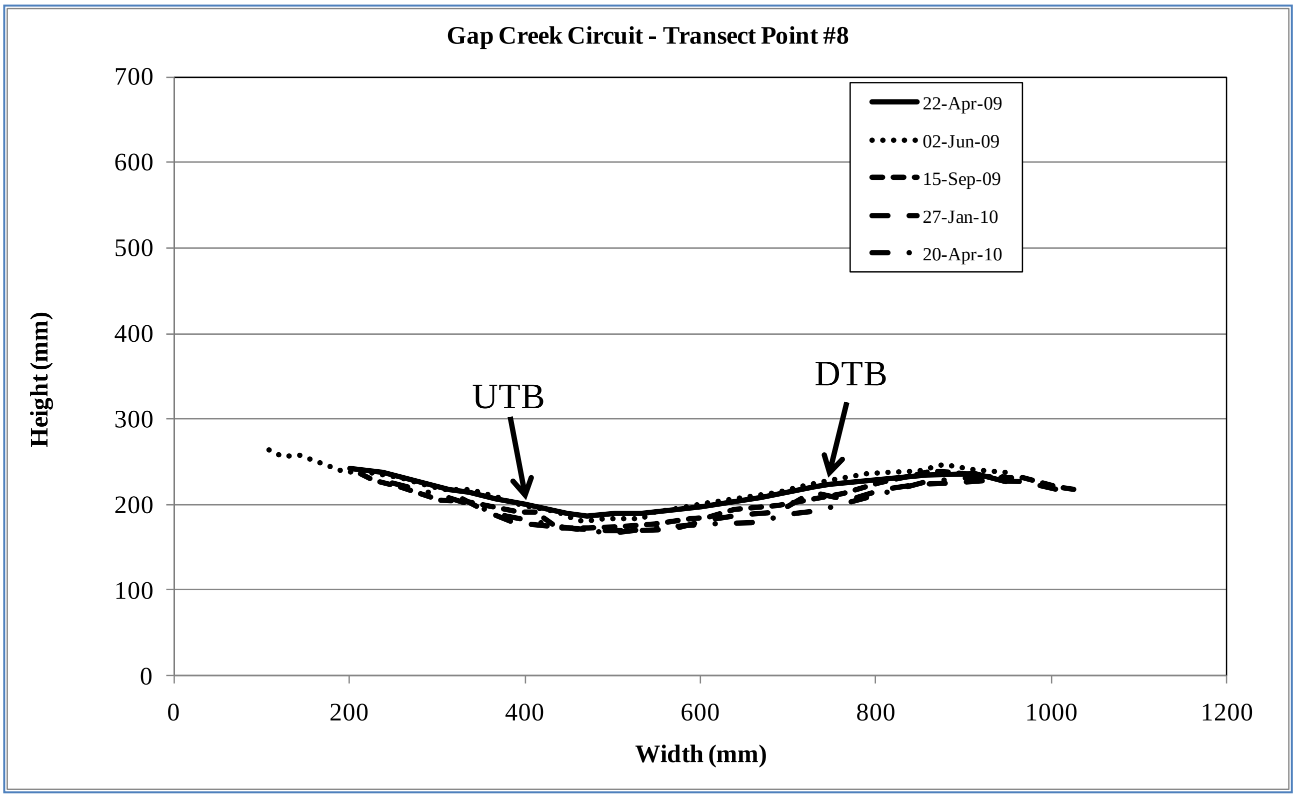

Figure 15 GCC-8 transect profile

The critical grade reversal is 9 metres from the transect point. Even though the trail gradient of 22 per cent is relatively steep (the guidelines indicate that this is fine for short sections of trail), the grade reversal appears to be close enough to produce a reasonably sustainable section of trail.

The profiles are reasonably consistent when the URP heights of surveys one and two are adjusted indicating minor soil loss in the used tread.

Conclusion: minor, insignificant change.

9.9 GCC-9

This is another transect point that is on an ascending section of trail with a surface of predominantly small, loose stones with some leaf and vegetation litter present. The profile is concave. The grade reversal is 12 metres away up a reasonably steep gradient of 13 per cent and the associated trail to fall line angle is an acceptable 75 degrees.

Both sets of mean change in profile area values indicate a minor loss of soil occurring in the used tread though this is not significant as the profiles are consistent.

The used tread width has barely altered over the study period.

Table 20 GCC-9 pertinent parameter values

Parameter	Value	Direction
Trail upslope gradient (%)	13	ToEnd
Trail to fall line angle (°)	75	
Used tread width change (%)	-1	

Table 21 GCC-9 mean changes in profile area for the used tread and the measuring limit

		Mean Change (cm^2/cm)	
Survey A	Survey B	Tread	ML
1	2	-0.4	-0.2
1	3	-0.5	-0.2
1	4	-1.8	-1.4
1	5	-2.3	-1.9

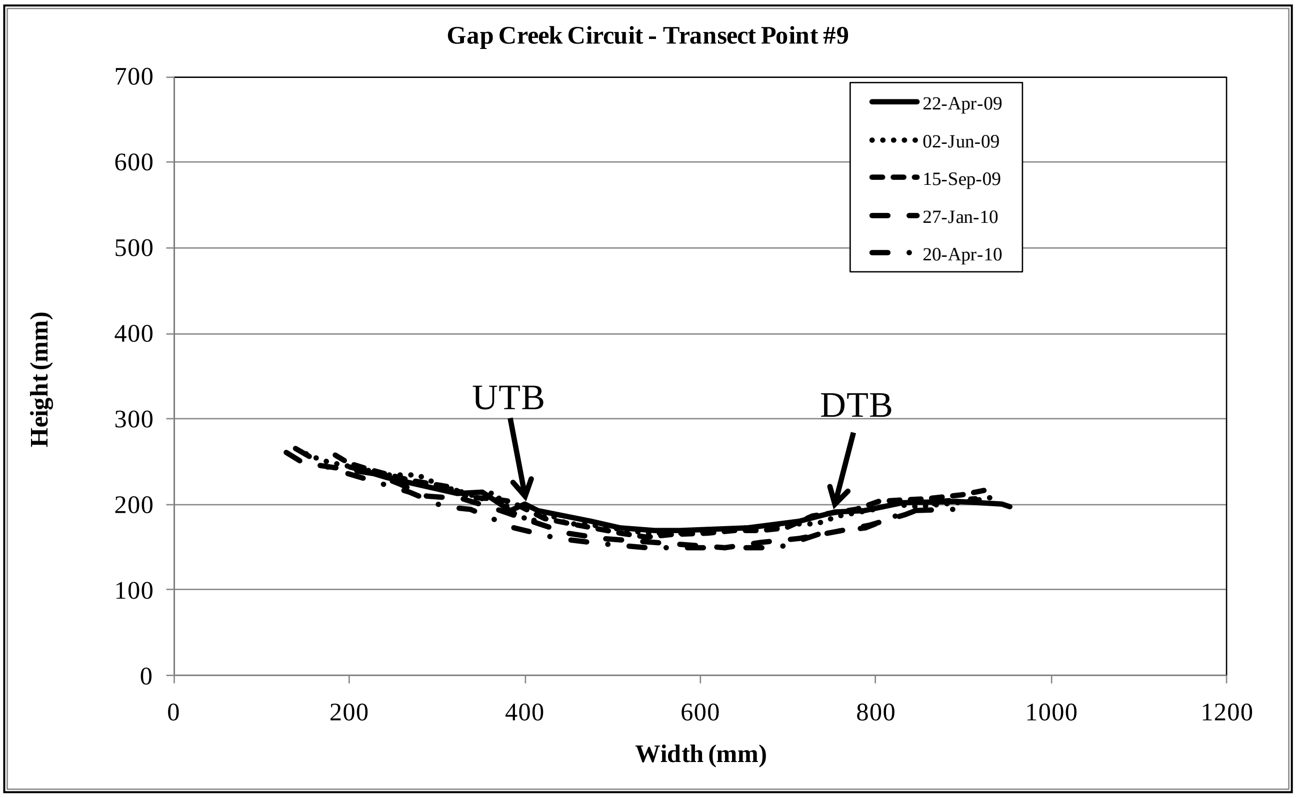

Figure 16 GCC-9 transect profile

Conclusion: minor, insignificant change.

9.10 GCC-10

This transect point is on a slightly rising curve of the trail about one metre past a drainage point. The distance to the upslope grade reversal is about 12 metres. The surface is packed earth, a few small loose stones and some leaf litter. The transect point appears not to have changed though the mean change in profile area values for the used tread indicate there may have been some soil gain between the fourth and fifth surveys. The used tread width was initially surprisingly narrow though the presence of a small tree just off the downside of the trail may play a part in restricting riders to the 21 cm of used tread as recorded in the baseline survey. The used tread did widen by 22 per cent to 26 cm by the fifth survey. The transect point is on a reasonably steep hillside with sideslope of about 40 per cent.

Table 22 GCC-10 pertinent parameter values

Parameter	Value	Direction
Trail upslope gradient (%)	3	ToEnd
Trail to fall line angle (°)	90	
Used tread width change (%)	22	

Table 23 GCC-10 mean changes in profile area for the used tread and the measuring limit

		Mean Change (cm^2/cm)	
Survey A	Survey B	Tread	ML
1	2	0.9	0.3
1	3	0.9	0.7
1	4	-0.2	-0.6
1	5	1.5	0.9

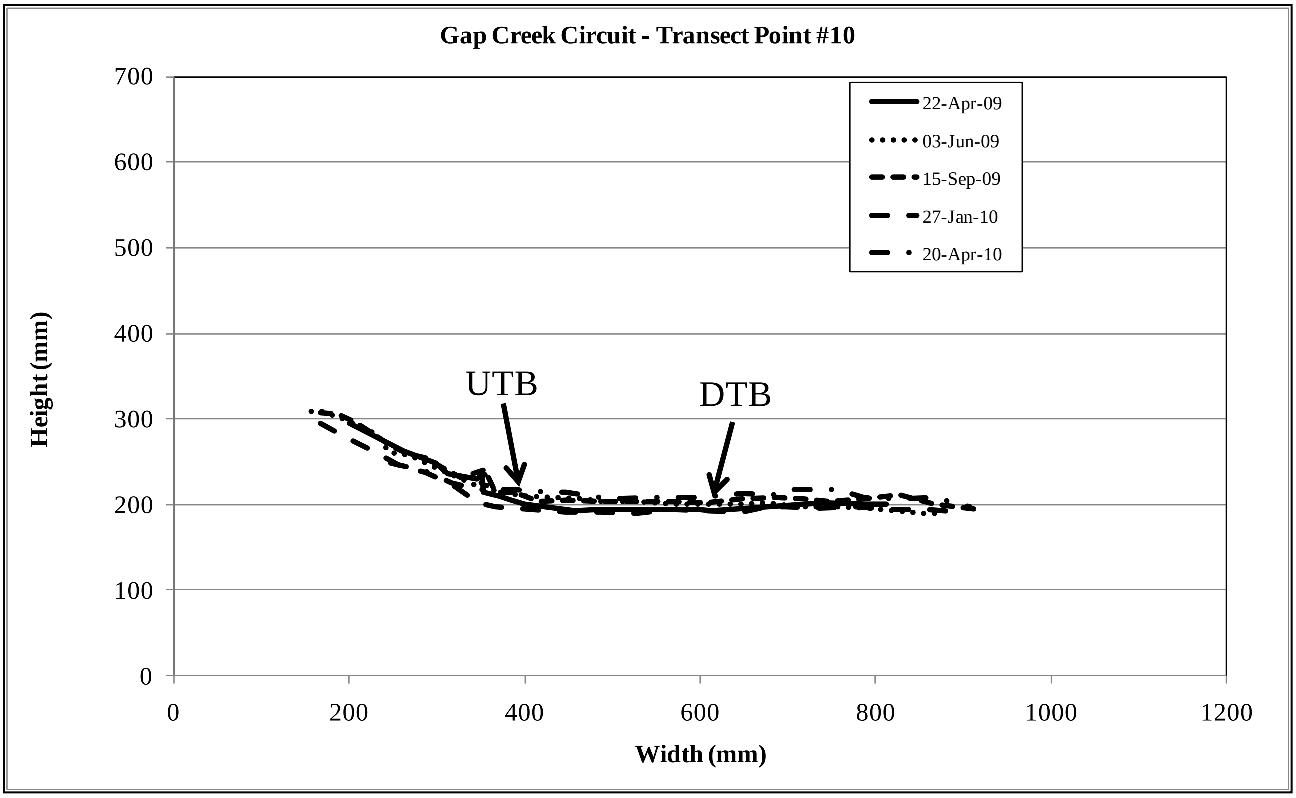

Figure 17 GCC-10 transect profile

Conclusion: no change.

9.11 GCC-11

This transect point is on a gentle gradient of 1 per cent on a gentle curve. Its surface is of packed earth with small, loose pebbles and the usual vegetation litter of leaves and small twig remnants. The upslope grade reversal is about 4 m away. The trail to fall line angle is 75°. The transect profile is concave and the profiles are a consistent shape. This is evidenced by changing the baseline survey URP reference height by 10 mm. This results in mean change values of -0.1, -1.2, -0.7, and -0.9 cm^2/cm for the used tread width and 0.2, -0.7, -0.5, and -0.6 cm^2/cm for the measuring limit. The values of the mean change in profile area indicate there may have been loss of soil between the first and third surveys over the used tread width but this is not evident from the values over the entire measuring width. These values, the photos and the inconsequential used tread width change of 3 per cent lead to the conclusion that there may have been some change at the transect but if so, it is insignificant.

Table 24 GCC-11 pertinent parameter values

Parameter	Value	Direction
Trail upslope gradient (%)	1	ToStart
Trail to fall line angle (°)	75	
Used tread width change (%)	3	

Table 25 GCC-11 mean changes in profile area for the used tread and the measuring limit

		Mean Change (cm^2/cm)	
Survey A	**Survey B**	**Tread**	**ML**
1	2	-1.1	-0.8
1	3	-2.2	-1.7
1	4	-1.7	-1.5
1	5	-1.9	-1.6

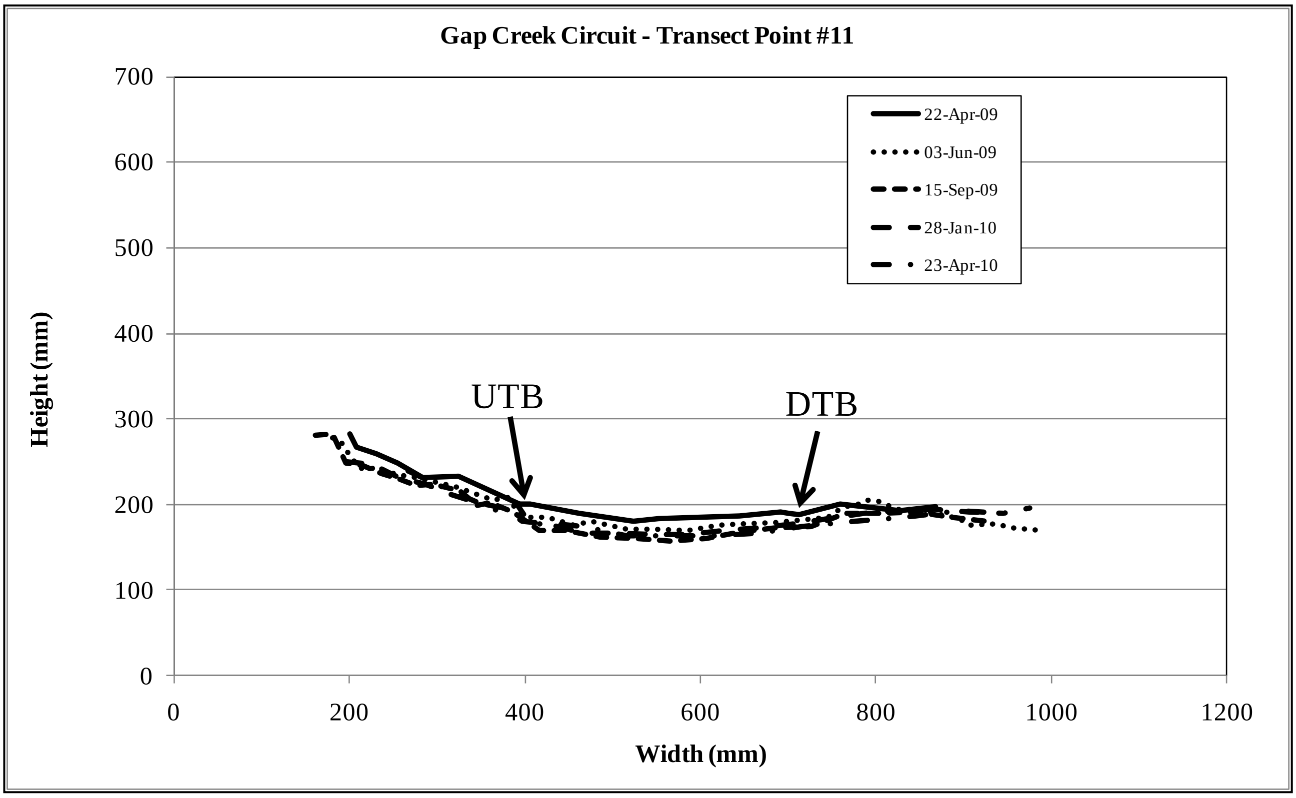

Figure 18 GCC-11 transect profile

Conclusion: minor, insignificant change.

9.12 GCC-12

The trail at this transect point is constrained on one side by a sharp drop and on the other by rocks. The rocks, the edge and a relatively small tree about two metres from the transect point constrict the riders on the trail and the used tread width reduced by 13 per cent over the study. The surface is of packed earth with some embedded stones, some small, loose stones, and leaf litter.

It was particularly difficult to set up the measuring apparatus at this transect point due to its proximity to the sharp drop on one side and the presence of rocks on the other. Positioning of the tripods so that they were stable was particularly troublesome as there was very little room within which to work on the side of the drop. The difficulty in measurement probably led to the large values of mean change in profile area (Table 27) that are at odds with the photographic evidence. In addition, the shapes of the profiles are consistent and changing the URP height of the baseline survey by 20 mm results in mean change values that indicate at worst the possibility only of minor, insignificant change (Table 28).

Table 26 GCC-12 pertinent parameter values

Parameter	Value	Direction
Trail upslope gradient (%)	4	ToEnd
Trail to fall line angle (°)	85	
Used tread width change (%)	-13	

Table 27 GCC-12 mean changes in profile area for the used tread and the measuring limit

		Mean Change (cm^2/cm)	
Survey A	Survey B	Tread	ML
1	2	-1.5	-2.0
1	3	-2.5	-2.8
1	4	-3.3	-2.8
1	5	-3.3	-3.1

Table 28 GCC-12 mean changes in profile area for the used tread and the measuring limit when the baseline URP height is changed by 20 mm

		Mean Change (cm^2/cm)	
Survey A	Survey B	Tread	ML
1	2	0.5	0.0
1	3	-0.5	-0.8
1	4	-1.3	-0.8
1	5	-1.3	-1.1

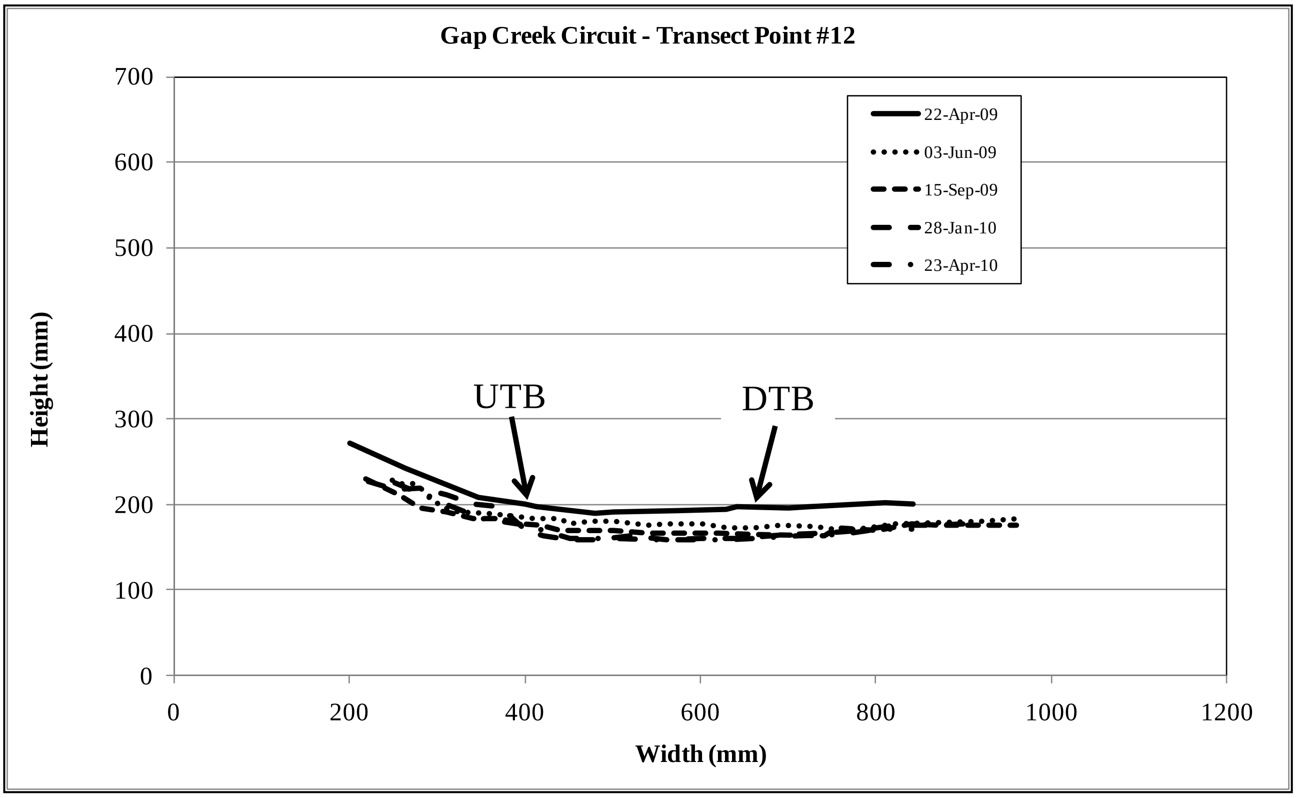

Figure 19 GCC-12 transect profile

In hindsight it would have been better to have not placed the transect point “by the book” (ie at the exact calculated distance from GCC-11) but moved it one metre closer to the start of the trail. Here the compounding effects of the drop and the rocks would very likely be considerably reduced. Consequently measurements at this more amenable location likely would have been much easier to obtain and hence errors would likely to have been reduced. A study of the photos reveals that neither the true transect point or this "hindsight" point exhibit signs of wear or erosion.

Figure 20 GCC-12 measurement setup

Conclusion: (possibly) minor, insignificant change.

9.13 GCC-13

The surface at this transect point has many loose, small stones on the top of packed earth with a few embedded stones. There is a considerable amount of leaf litter and remnants of twigs. The gradient is quite steep at 12 percent rising in the direction towards the end of the trail with the grade reversal about 3.5 metres away. The used tread width has increased by 50 per cent from a narrow 25 cm to 38 cm over the course of the study though where riders pass is well within the bounds of the trail as it was built.

The values of the mean change in profile area and the profiles indicate that there may have been noticeable change (soil loss) but the consistent profiles and photographic evidence point toward minor, insignificant change. Gouging of the trail surface has not occurred.

Table 29 GCC-13 pertinent parameter values

Parameter	Value	Direction
Trail upslope gradient (%)	12	ToEnd
Trail to fall line angle (°)	75	
Used tread width change (%)	50	

Table 30 GCC-13 mean changes in profile area for the used tread and the measuring limit

		Mean Change (cm²/cm)	
Survey A	Survey B	Tread	ML
1	2	0.5	0.6
1	3	-0.6	-0.5
1	4	-1.4	-1.2
1	5	-2.1	-1.8

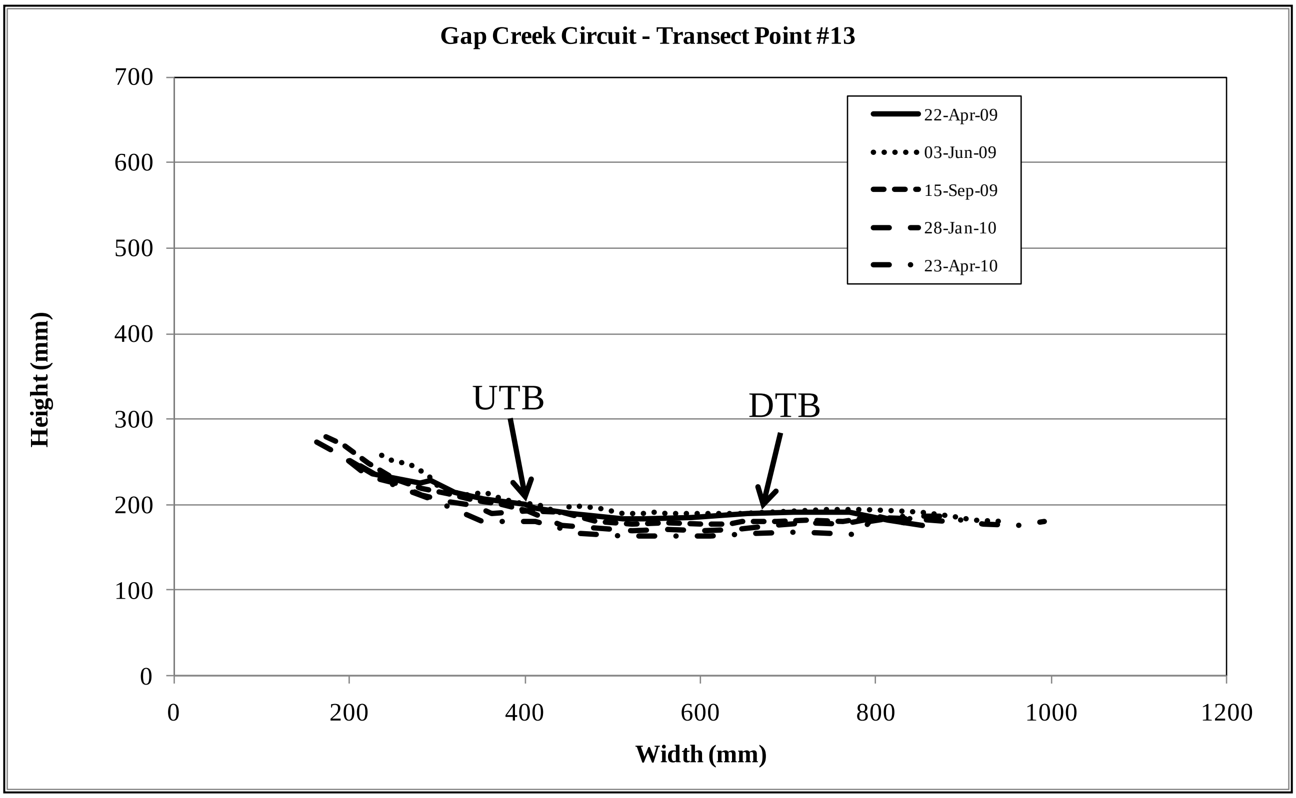

Figure 21 GCC-13 transect profile

Conclusion: minor, insignificant change.

9.14 GCC-14

The values of mean change in profile area show that there has been significant soil loss at this transect point over the course of the study, particularly between the fourth (January 2010) and fifth (April 2010) surveys. No deep gouging is evident. The point is situated on the point of a change of grade on a steep, short section of trail with a gradient of 11 per cent in the upslope direction and -20 per cent in the other and is about 6 metres from the upslope grade reversal. The surface is typically that of *Gap Creek Circuit* with packed earth, some small, loose stones and considerable leaf litter. The concave tread profile became more pronounced over the course of the study while the used tread width diminished by 27 per cent from about 32 cm to about 23 cm.

Table 31 GCC-14 pertinent parameter values

Parameter	Value	Direction
Trail upslope gradient (%)	11	ToEnd
Trail to fall line angle (°)	120	
Used tread width change (%)	-27	

Table 32 GCC-14 mean changes in profile area for the used tread and the measuring limit

		Mean Change (cm^2/cm)	
Survey A	Survey B	Tread	ML
1	2	-0.9	-0.9
1	3	-1.1	-1.2
1	4	-2.4	-2.3
1	5	-4.5	-4.2

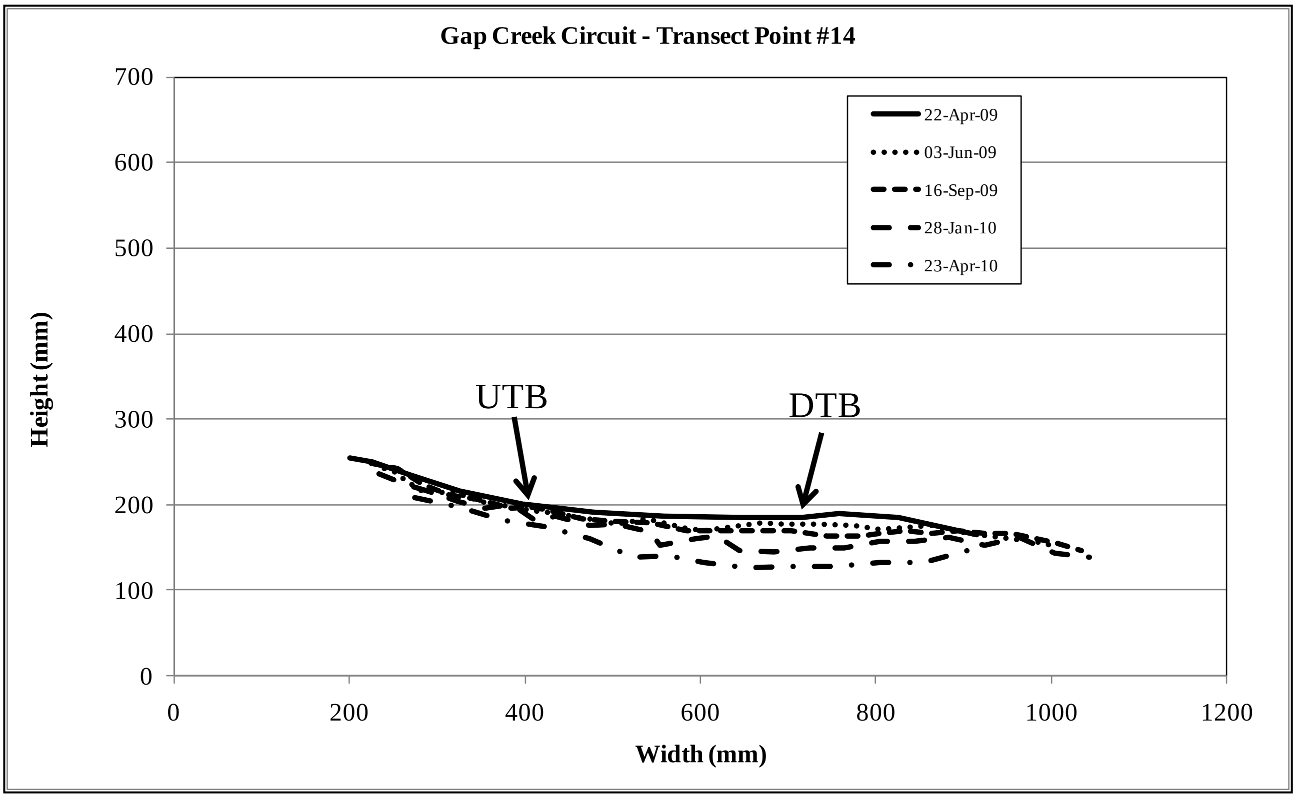

Figure 22 GCC-14 transect profile

Figure 23 GCC-14 in April 2009 and April 2010 showing the change in profile exaggerated by the angle of the sun

Conclusion: significant change (soil loss).

9.15 GCC-15

This transect point is very similar to GCC-14 in many respects: it is on a short, steep section of trail (18 per cent) not far from the upslope grade reversal; its surface is similar; and the profile has changed towards the downside of the used tread. As with GCC-14 the most soil loss occurred between the fourth (January 2010) and the fifth (April 2010) surveys. No deep gouging is evident. The values of the mean change in profile area show significant soil loss over the used tread and the measuring limit. The profiles indicate most of the loss has occurred towards the downside of the trail and into the area outside the tread as judged in the baseline study. The used tread width has increased only from 26 to 29 cm and its upper and downslope boundaries have altered little. The profile has become more concave over the course of the study. This transect point has a small trail to fall line angle of 40 degrees.

Figure 24 GCC-15 in April 2009 and April 2010 showing the change in profile

Table 33 GCC-15 pertinent parameter values

Parameter	Value	Direction
Trail upslope gradient (%)	18	ToEnd
Trail to fall line angle (°)	40	
Used tread width change (%)	13	

Table 34 GCC-15 mean changes in profile area for the used tread and the measuring limit

		Mean Change (cm^2/cm)	
Survey A	Survey B	Tread	ML
1	2	-0.8	-0.6
1	3	-1.1	-1.1
1	4	-2.6	-3.0
1	5	-4.0	-4.9

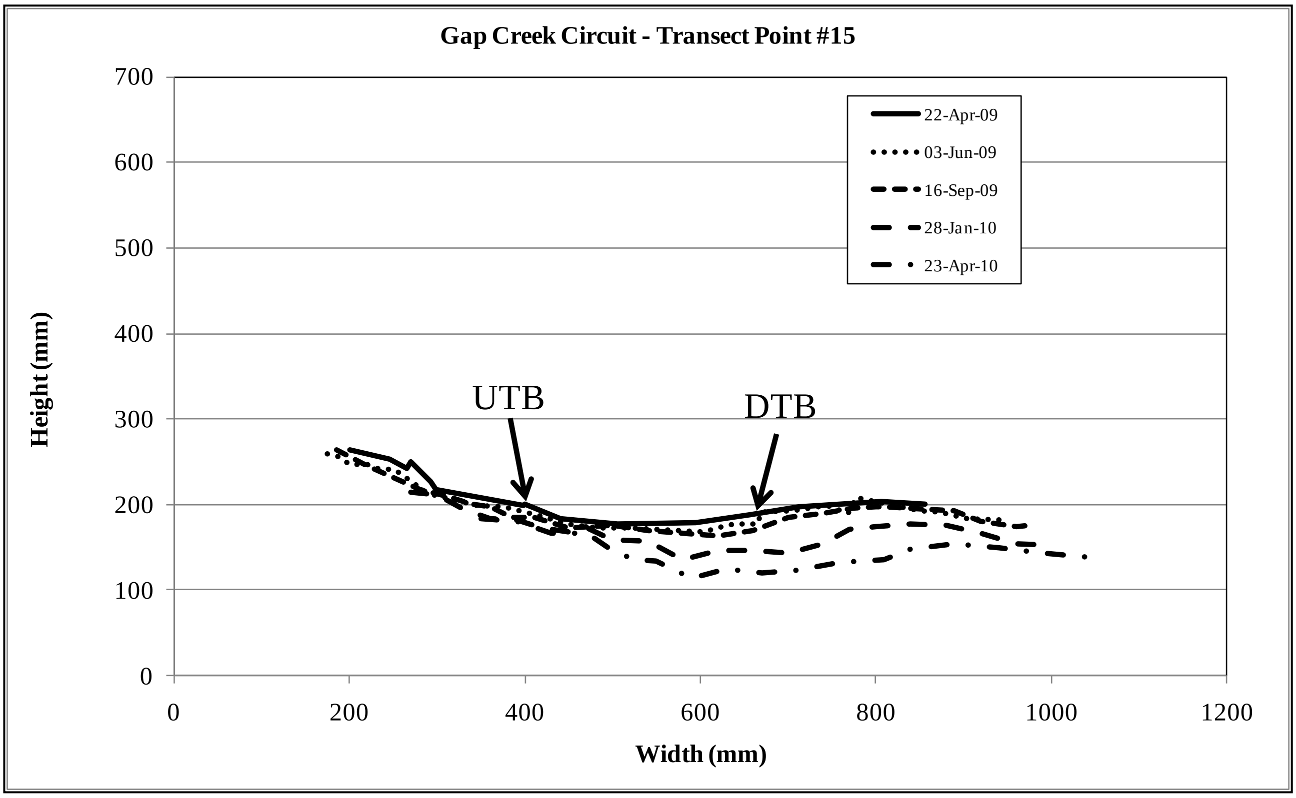

Figure 25 GCC-15 transect profile

Conclusion: significant change (soil loss).

9.16 GCC-16

This transect point is on a short, steep (20 per cent) section of trail about 6 metres down from the upslope grade reversal. There has been significant soil loss over the course of the study with the change being consistent over the year. This can be seen in the photographs and confirmed by the values of the mean change in profile area. These values increase by about 0.9 cm^2/cm from survey to survey. The profile is concave with change occurring well past the downside tread boundary throughout the year. No deep gouging is evident. The trail to fall line angle is quite small at 30 degrees and the used tread has increased slightly by 10 per cent from 30 to 33 cm.

Table 35 GCC-16 pertinent parameter values

Parameter	Value	Direction
Trail upslope gradient (%)	20	ToStart
Trail to fall line angle (°)	30	
Used tread width change (%)	10	

Table 36 GCC-16 mean changes in profile area for the used tread and the measuring limit

		Mean Change (cm^2/cm)	
Survey A	Survey B	Tread	ML
1	2	-1.0	-0.8
1	3	-1.8	-1.7
1	4	-2.9	-2.8
1	5	-3.5	-3.4

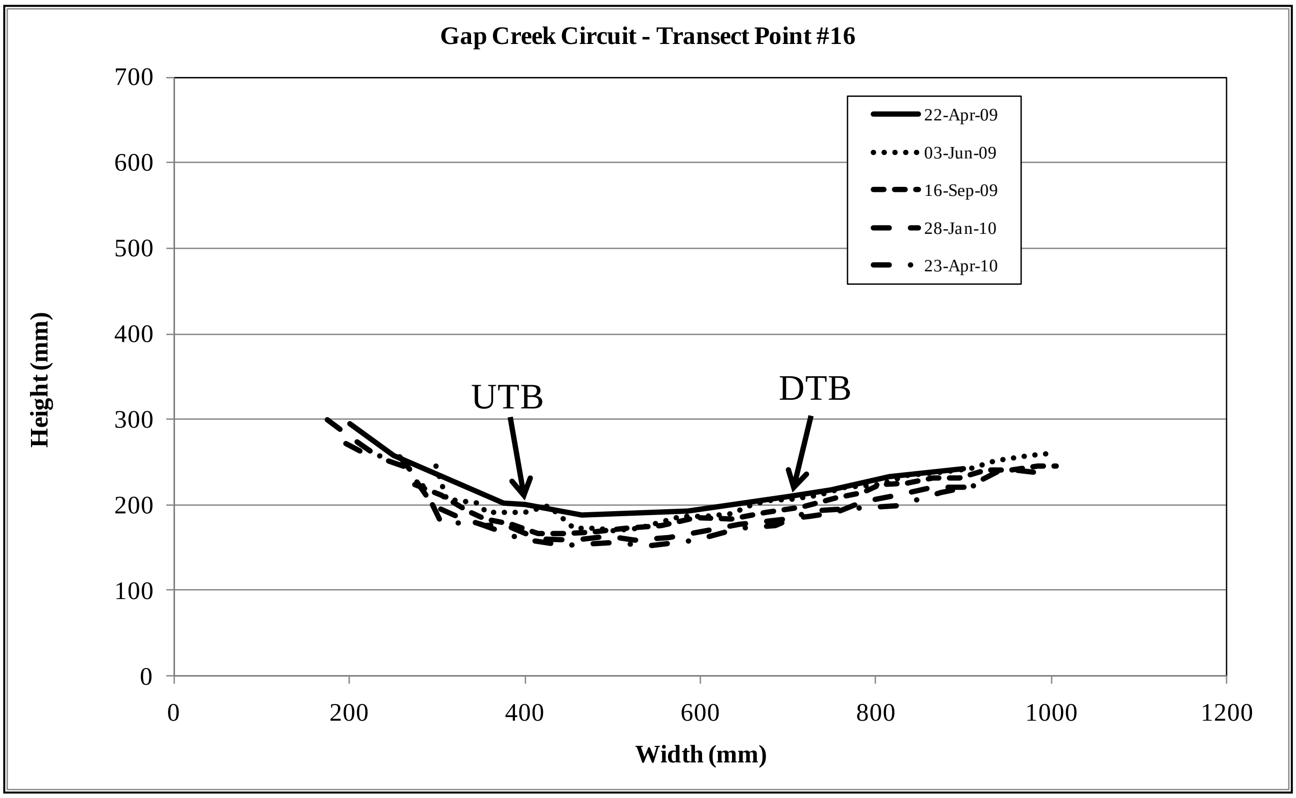

Figure 26 GCC-16 transect profile

Conclusion: significant change (soil loss).

9.17 GCC-17

Transect point GCC-17 exhibited no change over the study period. The transect profiles vary only within expected measurement variation as do the values of the mean change in profile area. The tread is nearly flat and the surface is the usual packed earth with several small, loose stones, leaf litter, and remnants of twigs.

Table 37   GCC-17 pertinent parameter values

Parameter	Value	Direction
Trail upslope gradient (%)	13	ToStart
Trail to fall line angle (°)	80	
Used tread width change (%)	22	

Table 38   GCC-17 mean changes in profile area for the used tread and the measuring limit

		Mean Change (cm^2/cm)	
Survey A	**Survey B**	**Tread**	**ML**
1	2	0.8	1.0
1	3	0.4	0.5
1	4	0.4	0.4
1	5	0.6	0.4

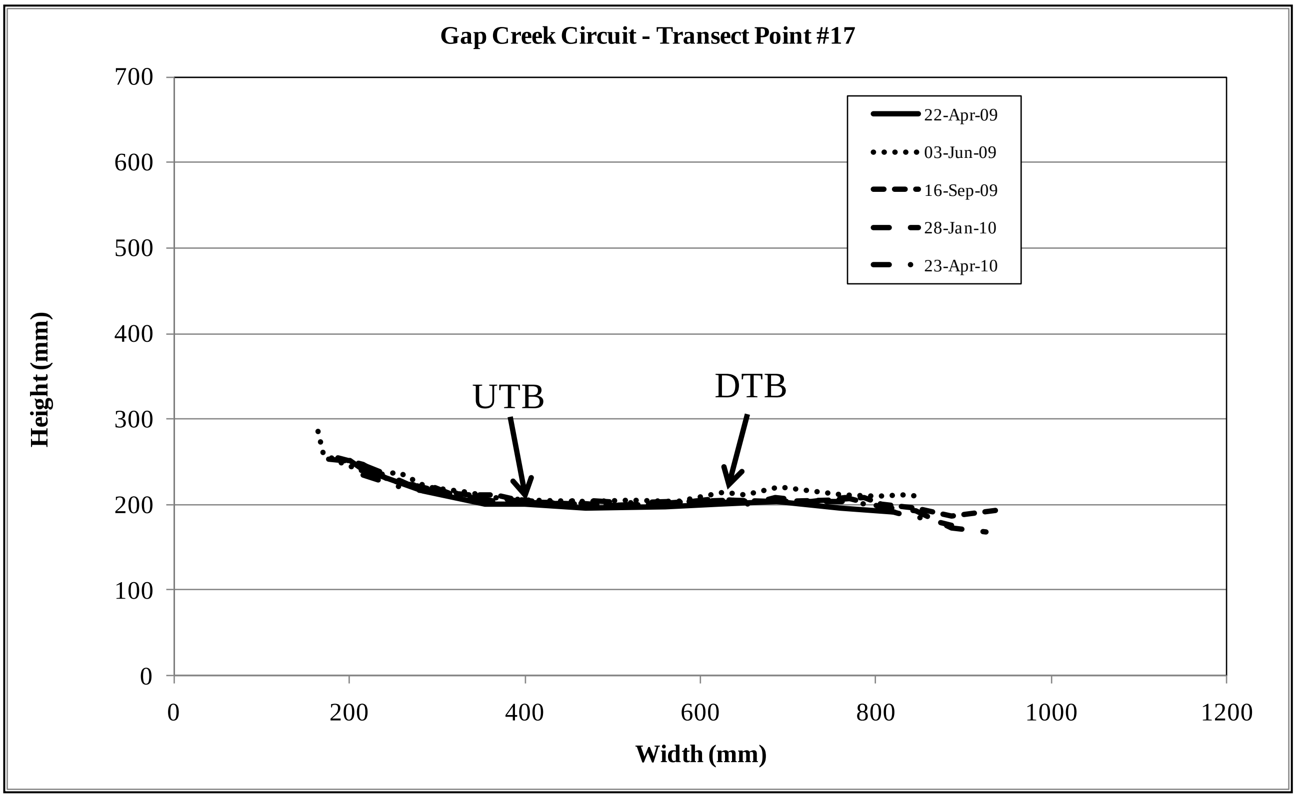

Figure 27   GCC-17 transect profile

Conclusion: no change.

9.18   GCC-18

Transect point GCC-18 is another that is very close to an upslope grade reversal: in this case very close indeed at only about 1 metre away. This section of trail is not steep at a gradient of 3 per cent and the transect point is adjacent to a substantial formation of embedded soft rock. No doubt this was used as a trail anchor point during construction and has resulted in the tread having a favourable outslope. Due to its close proximity to the formation of rocks, the surface comprises some embedded rocks and these undoubtedly help the durability of the tread. The rocks are the reason for the somewhat lumpy transect profiles shown in the graph. The values of mean change in profile area are well within the values resulting from acceptable measurement errors. Due to the hard surface, there is no change to the transect point.

Table 39 GCC-18 pertinent parameter values

Parameter	Value	Direction
Trail upslope gradient (%)	3	ToEnd
Trail to fall line angle (°)	70	
Used tread width change (%)	13	

Table 40 GCC-18 mean changes in profile area for the used tread and the measuring limit

		Mean Change (cm^2/cm)	
Survey A	Survey B	Tread	ML
1	2	0.7	0.5
1	3	0.2	-0.1
1	4	-0.4	-0.4
1	5	-0.8	-0.6

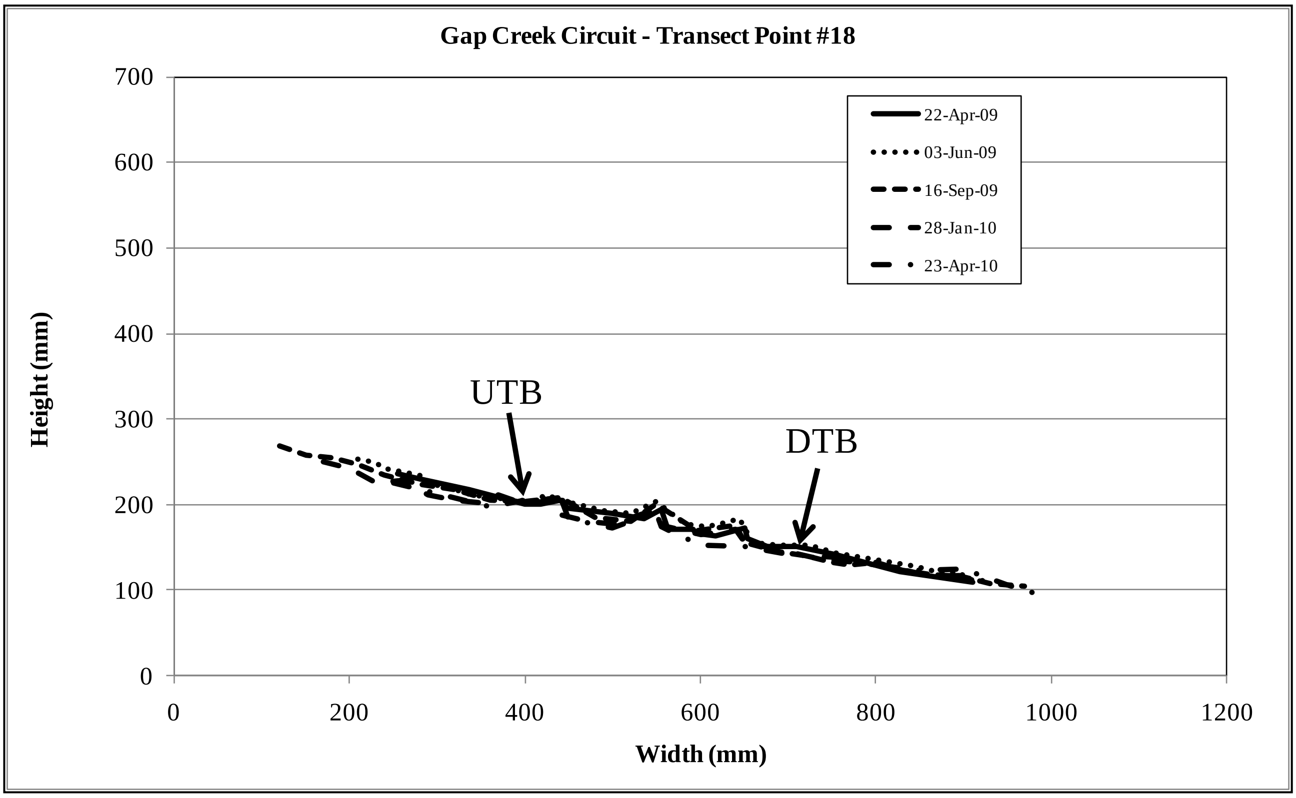

Figure 28 GCC-18 transect profile

Conclusion: no change.

9.19 GCC-19

This is another transect point that did not show any change over the study year as shown by the profiles and the values of mean change in profile area. The values are all within the range explained by differences in measuring technique.

The surface is of packed earth with several embedded stones and many small, loose stone.

The profile is slightly concave and the tread has a gentle outslope. The used tread width increased markedly over the study but it is likely that the baseline width was judged to be quite narrow in the first survey as the values from the later surveys are consistently between 34 and 40 cm.

Table 41 GCC-19 pertinent parameter values

Parameter	Value	Direction
Trail upslope gradient (%)	2	ToStart
Trail to fall line angle (°)	85	
Used tread width change (%)	73	

Table 42 GCC-19 mean changes in profile area for the used tread and the measuring limit

		Mean Change (cm^2/cm)	
Survey A	Survey B	Tread	ML
1	2	0.0	0.0
1	3	-0.4	-0.5
1	4	-0.6	-0.8
1	5	-0.4	-0.5

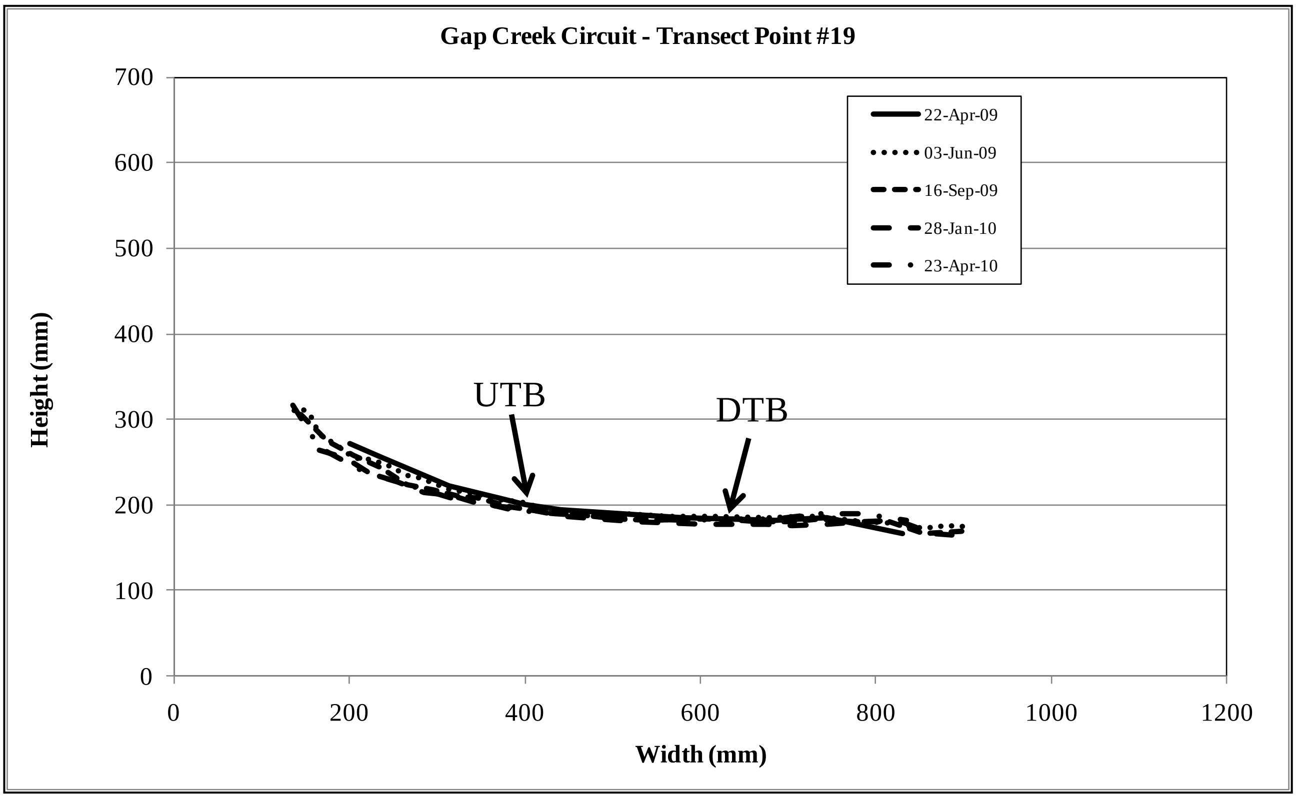

Figure 29 GCC-19 transect profile

Conclusion: no change.

9.20 GCC-20

Transect point GCC-20 is right on the apex of a rise and right next to a large tree. Hence there is no upslope gradient and the trail to fall line angle is 90 degrees. The profile is slightly concave and there has been no change in the transect.

Table 43 GCC-20 pertinent parameter values

Parameter	Value	Direction
Trail upslope gradient (%)	NA	

Trail to fall line angle (°)	90	
Used tread width change (%)	3	

Table 44 GCC-20 mean changes in profile area for the used tread and the measuring limit

		Mean Change (cm²/cm)	
Survey A	**Survey B**	**Tread**	**ML**
1	2	-0.5	-0.9
1	3	0.1	-0.2
1	4	-0.1	-0.2
1	5	-0.6	-0.6

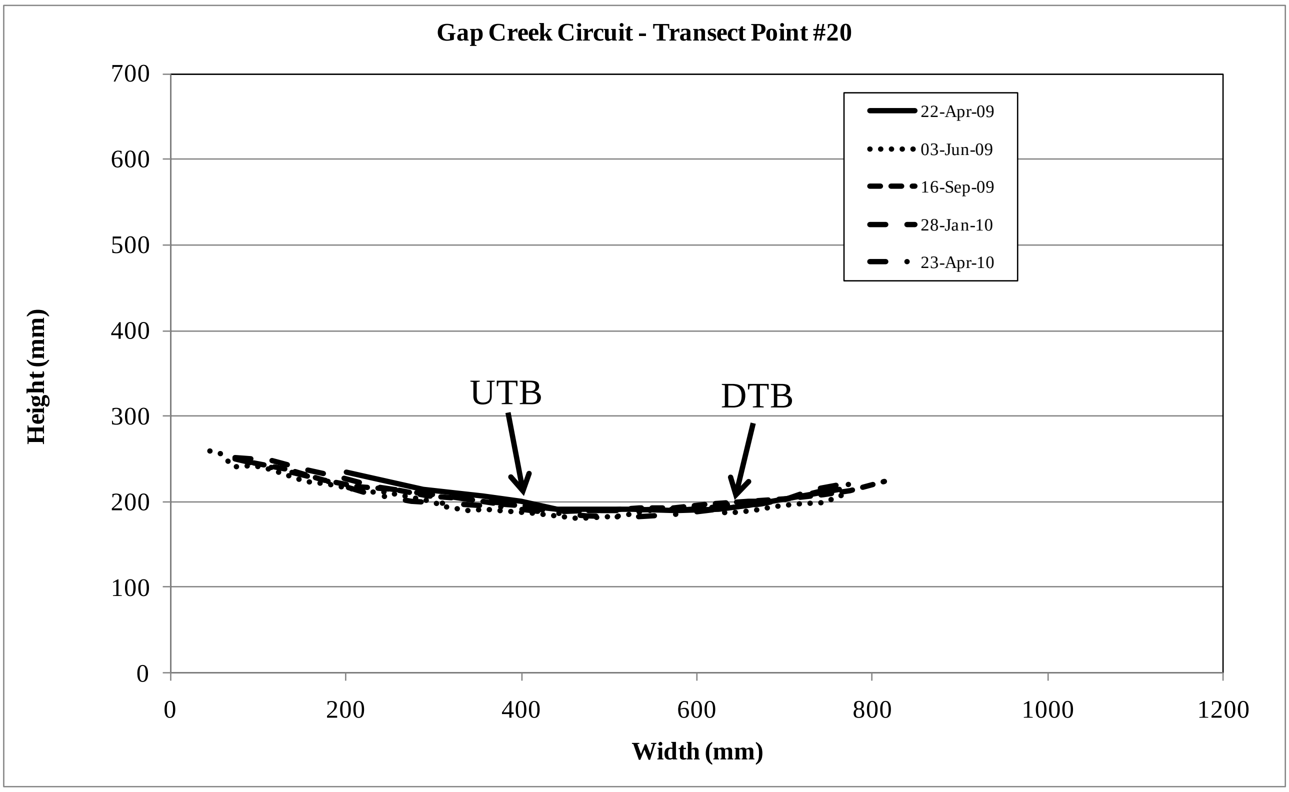

Figure 30 GCC-20 transect profile

Conclusion: no change.

9.21 Transect Point Analysis Summary

Of the 20 transect points on *Gap Creek Circuit*, ten showed no change discernible using the measurement and observation techniques of this study. Five showed minor but insignificant change. One of this five (GCC-12) was difficult to measure due to problems setting up the supporting tripods in a stable manner. It is possible that no change occurred at this point but the conservative conclusion of the possibility that there has been minor, insignificant change is made.

Of the twenty transect points, two (GCC-1 and GCC-3) indicated noticeable change with some soil loss.

The soil loss of GCC-1 did so over the transect from just upslope of the UTB to just downslope of the DTB. This is consistent with the observed increase in used tread width of nearly 40 per cent (from about 34 cm to about 48 cm). The calculated mean change in profile area values at GCC-1 were about the same from one survey to the next from the June 2009 survey through to the end.

For GCC-3, the mean change in profile area values indicate that the most soil loss occurred between the third (September 2009) and fourth (January 2010) surveys. A further much smaller soil loss occurred before the fifth (April 2010) survey. A stone originally positioned on the transect line was dislodged resulting in the inconsistent shape of the graphed profiles and accounting for much of the difference in profile area values.

The used tread width became narrower by 41 per cent over the course of the study with riders choosing a line closer to the downside of the trail though the downslope tread boundary did not alter significantly. It is towards this downside where the profile has altered.

Three transect points (GCC-14, GCC-15 and GCC-16) showed significant change. All three of these are on short, steep sections of trail. The trail gradient of GCC-14 is 11 per cent in one direction and -20 per cent in the other, while those of GCC-15 and GCC-16 are steep at about 18 and 20 per cent respectively.

For GCC-14, there was significant soil loss over the course of the study, and in particular between the fourth (January 2010) and fifth (April 2010) surveys (when about 42 per cent of the year's rainfall occurred and about 24 per cent of use was recorded). The concave tread profile became more pronounced over the course of the study while the used tread width diminished by 27 per cent from about 32 cm to about 23 cm.

One point to note about GCC-15 is that it has a small trail to fall line angle of 40 degrees. Significant soil loss occurred over the used tread and the measuring limit and the profile changed most towards the downside of the used tread. The most soil loss occurred between the fourth (January 2010) and the fifth (April 2010) surveys. The used tread width increased marginally from 26 to 29 cm and its upside and downside boundaries have altered little. The profile has become more concave over the course of the study.

The soil loss observed at GCC-16 occurred consistently over the course of the study with similar change values of about 0.9 cm^2/cm recorded from one survey to the next. The profile of the transect is concave with change occurring to past the downside tread boundary throughout the year. The trail to fall line angle is quite small at 30 degrees and the used tread has increased marginally by 10 per cent from 30 to 33 cm.

At none of the transect points, including those exhibiting noticeable or significant change, was there evidence of deep gouging.

10 Conclusions

Cross-country mountain bike trails in Australia are increasingly being built following the guidelines for sustainable trail building developed by the International Mountain Bicycling Association (IMBA) headquartered in the US. The guidelines are widely promoted by Mountain Bike Australia, the peak body for competitive mountain biking in Australia and by IMBA Australia.

One of the Queensland trails built to the guidelines is *Gap Creek Circuit*. This trail is situated in Mt Coot-tha Forest, in Brisbane, Queensland. Mt Coot-tha Forest is a large area of 1,500 hectares whose main entrance is about 6 km west of Brisbane's Central Business District. The forest extends about 7 km further west. It possesses grassed recreational areas, 31 km of shared-use trails and 18.5 km of walking trails that pass through a variety of types of vegetation. *Gap Creek Circuit* is part of a 12 km network of purpose-built, mountain bike only trails that has been designed and built with the IMBA guidelines in mind.

Gap Creek Circuit was the subject of a year-long monitoring and assessment program from April 2009 to April 2010.

The trail was selected because: (1) it was built to guidelines recognised internationally as producing the most sustainable trails; (2) a rider, once started would finish the trail and not take a detour – hence the entire trail would be subject to the same use; and (3) the trail was not to be subjected to maintenance work during the course of the study.

Trail tread transect profiles at 20 randomly-selected transect points were measured on five occasions over the year. The lengths of the inter-survey periods varied and were 42, 105, 138, and 85 days. Relevant topography parameters (trail gradient and bearing; sideslope gradient and bearing; fall line gradient and bearing; distance to the upslope grade reversal) at each point were measured. Values of the trail and fall line bearings enable calculation of the trail to fall line angle: one of the aims in building a sustainable trail to the guidelines is to have this angle as close to 90 degrees as possible.

At each transect point, changes in used tread width (where 95 per cent of riders would travel) were recorded concurrently with the transect profile measurements during each survey. The presence or otherwise of outslope was noted though not measured.

Rainfall was 1,135 mm over the course of the study. The portion of total rain (with amounts in millimetres shown in parentheses) that fell in each of the four inter-survey periods are 22 (249), 10 (116), 26 (289), and 42 (468) per cent.

Trail use was recorded using commercially-available in-ground counters specifically designed for recording the passage of mountain bikes. The accuracy of the counters was not calibrated against a manual check. The counters were not deployed until some time after the start of the study (deployed in June 2009). Nevertheless to gather a full year of use data, the counters were deployed until the appropriate date in June, 2010.

The first survey of measurements was performed in April 2009 and in May the trail was closed due to unusually heavy rain. The trail was re-opened in June 2009 at which time the trail use counters were deployed. Data collected over the period when counters were in place (June 2009 to June 2010) enabled an estimate of use as 31 passes per day. Daily use did not vary greatly over the counting year when the number of passes was divided by the length in days of the inter-survey counting period.

Since the position of the transect points was random some were sited on corners, some on straight parts of the trail, some on sloping sections, and some at grade reversals. The number of variables associated with transect point position (eg on a corner, on a straight etc) coupled with only 20 points for each trail means that grouping to produce meaningful statistical analysis within and between each group is not possible.

Ten (50 per cent) of the twenty transect points did not exhibit any change to the profiles and five (25 per cent) showed minor, insignificant change (soil movement) over the course of the study. A further two showed noticeable change (both with soil loss) and the remaining three (fifteen per cent) exhibited significant change (all with soil loss).

One of the points that showed significant change (GCC-14) is on a short, section of trail with a gradient of 11 per cent in the upslope direction and -20 per cent in the other and is about 6 metres from the upslope grade reversal. The trail surface is of packed earth, with some small, loose stones and considerable leaf litter. The profile changed towards the downside of the used tread but there was no evidence of deep gouging occurring. The most change occurred in the three month period between the fourth (January 2010) and fifth (April 2010) surveys when 42 per cent (480 mm) of the study period year's rain (1,135 mm) fell. This period accounted for a quarter of the total use.

The tread of this transect point was nearly outsloped at the start of the study and finished with a slightly concave tread (this is quite usual for a trail during its bedding-in period as is the case with *Gap Creek Circuit* at least during the early part of the study). As this became more concave it would have increasingly tended to channel water along the tread despite a reasonable trail to fall line angle that helps run the water across the trail. The trail at this transect point is built to conform to the IMBA guidelines and the exact reasons for the significant change can only be conjectured. One of the possible factors that can contribute to change is a steep sideslope but at this point the sideslope is only 25 degrees. Perhaps the area of hillside on the upside of the trail is deceptive in catching more water than appears and thereby contributes to more runoff onto this portion of trail than occurs at other sections and hence promotes erosion. Perhaps also the riding patterns of riders changed as evidenced by a reduction in the used tread width (where at least 95 per cent of riders travel) from 32 to 23 cm and this may have contributed to more wear than in other sections.

The other two transect points that showed significant change (GCC-15 and GCC-16) are also on steep sections of the trail (18 and 20 per cent) and had shallow trail to fall line angles (40 and 30 degrees). These values in concert push the envelope of good practice with respect to the trail building guidelines. The used tread widths at both of these transect points marginally increased.

To put "significant change (soil loss)" in perspective, at none of the transect points would the soil loss along a 1 cm wide strip across the trail tread overflow a common, garden trowel.

Of the two transect points that showed noticeable change, one, (GCC-3) is situated on a 16 per cent gradient section of trail with the grade reversal more than 10 metres uphill on the trail. The used tread width at the transect point reduced by about 40 per cent to 26 cm. This change in values of the mean change in profile area and the reduction in used tread width are largely due to the dislodgement of a large embedded stone between the third and fourth surveys. It is probable that the steepness of the trail at this transect point contributed to the stone being dislodged and this in turn would probably have caused riders to travel in a narrower part of the tread.

The other transect point that showed noticeable change (GCC-1) is on a much gentler slope of 8 per cent and is characterised by change occurring over quite a broad portion of the transect. This is reflected also in the increase in used tread width of about 40 per cent. The point is at the end of a section of trail that would allow and probably encourage riders to obtain a reasonable speed and it is likely that braking of a fairly aggressive nature occurs at the transect point. Additionally, the grade reversal is much more than ten metres upslope on the trail. A further profile measurement performed in August 2010 indicates that no more change had occurred since the April 2010 survey.

At none of the 20 transect points was there evidence of gouging, deep wheel ruts or channels caused by erosion.

Of the twenty transect points on *Gap Creek Circuit* nine did not show marked change to the used tread width. That is, the change was within ±15 per cent of the tread width of the baseline survey. Five became narrower by 20 to 41 per cent. Four became wider by 22 to 38 per cent, one widened by 50 per cent and one by 73 per cent. None of the treads that changed did so outside the edge of the trail as built and hence none showed signs of tread creep.

The used tread widths varied from 21 to 48 cm and the mean used tread width increased insignificantly from 30 to 31 cm over the year of the study.

Overall, 45 per cent of the transect points showed no change in used tread width, 25 per cent narrowed noticeably and 30 per cent widened noticeably.

In summary, the physical properties (transect profiles and used tread widths) of trails built to conform to the IMBA guidelines indicate that for the most part trails in Mt Coot-tha Forest can withstand the combination of about 30 passes per day and 1,135 mm of rain per annum for at least one year with little impact on the trail surface or the width of the used portion of the trail. While continual maintenance of trails is always required, maintenance is likely to be required more often in those parts of trails that deviate too far from the guidelines while trail sections built within the guidelines will consume much less of the trail maintenance budget.

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Transect Point Parameter Data

and

Survey Dates

and

Rainfall Data

Appendices to the report

Gap Creek Circuit Mountain Bike Trail:
Long Term Environmental and Use Impacts

prepared for

Gap Creek Trails Alliance

by

Stuart Clement Solutions

Adelaide

South Australia

22 October 2010

Appendices

Appendix A: Transect Point Parameter Data

The topographical details of tables such as Table 45 give a picture of how the transect point is situated on the trail and on the hillside. From the data, the reader can ascertain what a rider would experience approaching and leaving the point and an idea of the slope of the hillside.

Trail gradients and bearings are taken referenced from the transect point and sideslope and fall line gradients and bearings are taken with reference to points at the sides of the trail on the transect line on the undisturbed slope of the hillside.

The topography information of Table 45 indicate that a rider travelling in the nominated direction of the trail (ie in the ToEnd trail direction) would approach the transect point on a descending grade of 8 per cent at a bearing of 5°. From the transect point, the rider would turn left through 35° and descend at a gradient of 21 per cent for about 3 metres.

While standing on the trail at the transect point a person would see the grade reversal more than 10 metres looking back towards the start of the trail at a bearing of 185 degrees. Turning around and looking towards the end of the trail, a person would note that the upslope of the hillside was on the right. Looking directly along the transect line the upslope gradient would appear as 19 per cent at an bearing of 80 degrees and would have a consistent grade (no intervening bumps or hollows) up to about 4 metres away. The fall line is on a different bearing (115 degrees) and is steeper at 27 per cent than the sideslope gradient which is at 19 per cent.

The trail to fall line angle of 70° is the difference between the positive trail gradient bearing (185°) and the upslope fall line bearing (115°). The difference in gradient between the trail and the fall line is 19 per cent.

Table 45 GCC-1 transect point topography

Topography Element	Direction	Side (L/R)	Gradient (%)	Bearing (°)	Distance (m)	Grade Reversal Distance (m)
Trail	**To End**		-21	330	3	
	To Start		8	185	4	>10
Sideslope	**Upslope**	R	19	80	5	
	Downslope	L	-23	260	4	
Fall line	**Upslope**	R	27	115	4	
	Downslope	L	-25	295	4	
Trail to Fall Line Angle (°)				70		

Table 46 gives the distances of the reference points as measured for each of the surveys. Table 46 also contains the measuring limit boundaries used to calculate the wider cross-sectional profile area. These boundaries are between the maximum value of UML and the minimum value of DML. The measuring limits for each of the surveys are also shown.

Also in Table 46 are the used tread widths and the percentage change of that measured at each survey compared with that measured at the baseline survey. As noted in the body of the report, the used tread boundaries for Survey 2 were extremely difficult to ascertain as the trail had been closed for 14 days prior to the survey and hence there were no marks on the trail that could be attributed to mountain bikes. The UTB and DTB for all transect points for Survey #2 should be treated as rough guesses only; hence no attempt is made in this report to calculate the percentage change in used tread width for Survey #2 in comparison with the baseline survey.

Table 46 GCC-1 reference point distances and measuring widths

Reference Point	Distance from URP (cm)					
	Survey #1	Survey #2	Survey #3	Survey #4	Survey #5	ML Calc
UML	45	28	33	40	29	45
UTB	65	48	53	60	49	
DTB	99	112	98	104	96	
DML	119	132	118	124	116	116
Width (cm)						
Tread	34	64	44	44	48	
% Change	---	---	29	28	38	
ML	74	104	84	84	108	71

This transect point is at the foot of a dip and hence has two trail to fall line angles.

Table 47 GCC-2 transect point topography

Topography Element	Direction	Side (L/R)	Gradient (%)	Bearing (°)	Distance (m)	Grade Reversal Distance (m)
Trail	**To End**		6	255	2	10
	To Start		9	95	6	>10
Sideslope	**Upslope**	L	15	190	4	
	Downslope	R	-17	10	4	
Fall line	**Upslope**	L	18	145	4	
	Downslope	R	-18	325	4	
Trail to Fall Line Angle (°)				50		
Trail to Fall Line Angle (°)				110		

Table 48 GCC-2 reference point distances and measuring widths

Reference Point	Distance from URP (cm) Survey #1	Survey #2	Survey #3	Survey #4	Survey #5	ML Calc
UML	54	52	52	46	67	67
UTB	74	72	72	66	87	
DTB	110	116	110	105	116	
DML	130	136	130	125	136	125
Width (cm)						
Tread	36	44	38	39	29	
% Change	---	---	6	8	-20	
ML	76	84	78	79	69	58

Table 49 GCC-3 transect point topography

Trail Name	Gap Creek Circuit		**Transect Point #**		3	
Topography Element	**Direction**	**Side (L/R)**	**Gradient (%)**	**Bearing (°)**	**Distance (m)**	**Grade Reversal Distance (m)**
Trail	**To End**		-16	190	2	>10
	To Start		16	0	3	>10
Sideslope	**Upslope**	L	45	95	4	
	Downslope	R	-45	275	3	
Fall line	**Upslope**	L	50	75	4	
	Downslope	R	-47	255	3	
Trail to Fall Line Angle (°)				75		

Table 50 GCC-3 reference point distances and measuring widths

Reference Point	**Distance from URP (cm)** **Survey #1**	**Survey #2**	**Survey #3**	**Survey #4**	**Survey #5**	**ML Calc**
UML	49	54	62	67	71	71
UTB	69	74	82	86	91	
DTB	113	118	122	126	117	
DML	133	138	136	146	137	133
Width (cm)						
Tread	44	44	40	40	26	
% Change	---	---	-9	-9	-41	
ML	84	84	74	79	66	62

Table 51 GCC-4 transect point topography

Trail Name	Gap Creek Circuit		Transect Point #		4	
Topography Element	**Direction**	**Side (L/R)**	**Gradient (%)**	**Bearing (°)**	**Distance (m)**	**Grade Reversal Distance (m)**
Trail	**To End**		3	260	3	3
	To Start		-5	90	3.2	
Sideslope	**Upslope**	L	29	180	4	
	Downslope	R	-29	0	4	
Fall line	**Upslope**	L	28	180	4	
	Downslope	R	-29	0	4	
Trail to Fall Line Angle (°)				80		

Table 52 GCC-4 reference point distances and measuring widths

Reference Point	Distance from URP (cm) Survey #1	Survey #2	Survey #3	Survey #4	Survey #5	ML Calc
UML	50	49	44	44	48	50
UTB	70	69	64	64	68	
DTB	97	100	101	93	99	
DML	117	120	121	113	119	113
Width (cm)						
Tread	27	30	37	29	30	
% Change	---	---	36	8	13	
ML	67	70	77	69	70	63

Table 53 GCC-5 transect point topography

Trail Name	Gap Creek Circuit		Transect Point #		5	
Topography Element	**Direction**	**Side (L/R)**	**Gradient (%)**	**Bearing (°)**	**Distance (m)**	**Grade Reversal Distance (m)**
Trail	**To End**		2	205	8	8
	To Start		0	30	1.6	
Sideslope	**Upslope**	L	22	120	4	
	Downslope	R	-22	300	3	
Fall line	**Upslope**	L	22	125	4	
	Downslope	R	-22	315	3	
Trail to Fall Line Angle (°)				80		

Table 54 GCC-5 reference point distances and measuring widths

Reference Point	**Distance from URP (cm)** Survey #1	Survey #2	Survey #3	Survey #4	Survey #5	ML Calc
UML	49	50	49	50	48	50
UTB	69	70	69	70	68	
DTB	105	106	97	97	95	
DML	125	126	117	117	115	115
Width (cm)						
Tread	36	36	28	27	27	
% Change	---	---	-24	-25	-26	
ML	76	76	68	67	67	65

Table 55 GCC-6 transect point topography

Trail Name	Gap Creek Circuit		Transect Point #		6	
Topography Element	**Direction**	**Side (L/R)**	**Gradient (%)**	**Bearing (°)**	**Distance (m)**	**Grade Reversal Distance (m)**
Trail	**To End**		0	305	3	
	To Start		6	135	3	3
Sideslope	**Upslope**	L	30	220	5	
	Downslope	R	-30	45	4.5	
Fall line	**Upslope**	L	30	220	5	
	Downslope	R	-30	45	4.5	
Trail to Fall Line Angle (°)				85		

Table 56 GCC-6 reference point distances and measuring widths

Reference Point	**Distance from URP (cm)** Survey #1	**Survey #2**	**Survey #3**	**Survey #4**	**Survey #5**	**ML Calc**
UML	58	56	66	52	57	66
UTB	78	76	86	72	77	
DTB	121	125	117	107	110	
DML	141	145	137	127	130	127
Width (cm)						
Tread	43	49	31	35	34	
% Change	---	---	-27	-18	-21	
ML	83	89	71	75	74	61

This transect point is at the foot of a dip and hence has two trail to fall line angles.

Table 57 GCC-7 transect point topography

Trail Name	Gap Creek Circuit		**Transect Point #**		7	
Topography Element	**Direction**	**Side (L/R)**	**Gradient (%)**	**Bearing (°)**	**Distance (m)**	**Grade Reversal Distance (m)**
Trail	**To End**		6	220	9	
	To Start		6	40	2	2
Sideslope	**Upslope**	L	28	140	4	
	Downslope	R	-24	312	5	
Fall line	**Upslope**	L	29	152	3.5	
	Downslope	R	-27	340	5.5	
Trail to Fall Line Angle (°)				112		
Trail to Fall Line Angle (°)				68		

Table 58 GCC-7 reference point distances and measuring widths

Reference Point	**Distance from URP (cm)** Survey #1	**Survey #2**	**Survey #3**	**Survey #4**	**Survey #5**	**ML Calc**
UML	45	39	47	40	38	47
UTB	65	59	67	60	58	
DTB	93	100	100	91	87	
DML	113	120	120	111	107	107
Width (cm)						
Tread	28	41	33	31	29	
% Change	---	---	17	11	4	
ML	68	81	73	71	69	60

Table 59 GCC-8 transect point topography

Trail Name	Gap Creek Circuit		**Transect Point #**		8	
Topography Element	**Direction**	**Side (L/R)**	**Gradient (%)**	**Bearing (°)**	**Distance (m)**	**Grade Reversal Distance (m)**
Trail	**To End**		22	225	3.5	9
	To Start		-13	65	3	3
Sideslope	**Upslope**	L	35	145	3.5	
	Downslope	R	-27	325	5	
Fall line	**Upslope**	L	36	170	5	
	Downslope	R	-30	0	4.5	
Trail to Fall Line Angle (°)				55		

Table 60 GCC-8 reference point distances and measuring widths

Reference Point	**Distance from URP (cm)** Survey #1	**Survey #2**	**Survey #3**	**Survey #4**	**Survey #5**	**ML Calc**
UML	59	50	60	72	64	72
UTB	79	70	80	92	84	
DTB	114	114	123	120	116	
DML	134	134	143	140	136	134
Width (cm)						
Tread	35	44	43	28	32	
% Change	---	---	22	-20	-9	
ML	75	84	83	68	72	62

Table 61 GCC-9 transect point topography

Trail Name	Gap Creek Circuit		**Transect Point #**		9	
Topography Element	**Direction**	**Side (L/R)**	**Gradient (%)**	**Bearing (°)**	**Distance (m)**	**Grade Reversal Distance (m)**
Trail	**To End**		13	240	2	12
	To Start		-7	60	4	
Sideslope	**Upslope**	L	32	145	5	
	Downslope	R	-21	320	4	
Fall line	**Upslope**	L	37	165	5	
	Downslope	R	-25	345	5	
Trail to Fall Line Angle (°)				75		

Table 62 GCC-9 reference point distances and measuring widths

Reference Point	**Distance from URP (cm)** **Survey #1**	**Survey #2**	**Survey #3**	**Survey #4**	**Survey #5**	**ML Calc**
UML	69	64	68	62	63	69
UTB	89	84	88	82	83	
DTB	125	122	122	121	118	
DML	145	142	142	141	138	138
Width (cm)						
Tread	35	38	35	39	35	
% Change	---	---	-2	9	-1	
ML	75	78	75	79	75	69

This transect point is at the foot of a dip and hence has two trail to fall line angles.

Table 63 GCC-10 transect point topography

Trail Name	Gap Creek Circuit		**Transect Point #**		10	
Topography Element	**Direction**	**Side (L/R)**	**Gradient (%)**	**Bearing (°)**	**Distance (m)**	**Grade Reversal Distance (m)**
Trail	**To End**		3	240	2	12
	To Start		9	65	1	
Sideslope	**Upslope**	L	40	150	5	
	Downslope	R	-42	330	4	
Fall line	**Upslope**	L	40	150	5	
	Downslope	R	-42	330	4	
Trail to Fall Line Angle (°)				90		
Trail to Fall Line Angle (°)				85		

Table 64 GCC-10 reference point distances and measuring widths

Reference Point	**Distance from URP (cm)** Survey #1	**Survey #2**	**Survey #3**	**Survey #4**	**Survey #5**	**ML Calc**
UML	63	59	60	60	68	68
UTB	83	79	80	80	88	
DTB	105	111	115	113	114	
DML	125	131	135	133	134	125
Width (cm)						
Tread	21	32	35	33	26	
% Change	---	---	64	55	22	
ML	61	72	75	73	66	57

Table 65 GCC-11 transect point topography

Trail Name	Gap Creek Circuit		Transect Point #		11	
Topography Element	**Direction**	**Side (L/R)**	**Gradient (%)**	**Bearing (°)**	**Distance (m)**	**Grade Reversal Distance (m)**
Trail	**To End**		-6	225	5	
	To Start		1	70	4	
Sideslope	**Upslope**	L	43	145	4	
	Downslope	R	-44	325	4	
Fall line	**Upslope**	L	43	145	4	
	Downslope	R	-44	325	4	
Trail to Fall Line Angle (°)				75		

Table 66 GCC-11 reference point distances and measuring widths

Reference Point	Distance from URP (cm) Survey #1	Survey #2	Survey #3	Survey #4	Survey #5	ML Calc
UML	65	64	62	65	72	72
UTB	85	84	82	85	92	
DTB	116	124	118	120	123	
DML	132	144	138	140	143	132
Width (cm)						
Tread	30	41	37	35	31	
% Change	---	---	21	16	3	
ML	67	81	77	75	71	60

Table 67 GCC-12 transect point topography

Trail Name	Gap Creek Circuit		Transect Point #		12	
Topography Element	**Direction**	**Side (L/R)**	**Gradient (%)**	**Bearing (°)**	**Distance (m)**	**Grade Reversal Distance (m)**
Trail	**To End**		4	275	3	3
	To Start		-6	100	1.5	
Sideslope	**Upslope**	L	57	190	5	
	Downslope	R	-64	10	4	
Fall line	**Upslope**	L	57	190	5	
	Downslope	R	-64	10	4	
Trail to Fall Line Angle (°)				85		

Table 68 GCC-12 reference point distances and measuring widths

Reference Point	Distance from URP (cm) Survey #1	Survey #2	Survey #3	Survey #4	Survey #5	ML Calc
UML	16	21	18	18	21	21
UTB	36	41	38	38	41	
DTB	60	72	72	66	62	
DML	80	92	92	86	80	80
Width (cm)						
Tread	24	31	34	28	21	
% Change	---	---	40	16	-13	
ML	64	71	74	68	59	59

Table 69 GCC-13 transect point topography

Trail Name	Gap Creek Circuit		Transect Point #		13	
Topography Element	**Direction**	**Side (L/R)**	**Gradient (%)**	**Bearing (°)**	**Distance (m)**	**Grade Reversal Distance (m)**
Trail	**To End**		12	20	3.5	3.5
	To Start		-12	195	2	
Sideslope	**Upslope**	L	30	280	4	
	Downslope	R	-23	100	4	
Fall line	**Upslope**	L	30	305	4	
	Downslope	R	-24	115	4	
Trail to Fall Line Angle (°)				75		

Table 70 GCC-13 reference point distances and measuring widths

Reference Point	Distance from URP (cm) Survey #1	Survey #2	Survey #3	Survey #4	Survey #5	ML Calc
UML	57	61	54	53	58	61
UTB	77	81	74	73	78	
DTB	102	111	102	105	116	
DML	122	131	122	125	136	122
Width (cm)						
Tread	25	31	27	32	38	
% Change	---	---	8	26	50	
ML	65	71	67	72	78	61

Table 71 GCC-14 transect point topography

Trail Name	Gap Creek Circuit		Transect Point #			
Topography Element	**Direction**	**Side (L/R)**	**Gradient (%)**	**Bearing (°)**	**Distance (m)**	**Grade Reversal Distance (m)**
Trail	**To End**		11	0	4	6
	To Start		-20	180	4	
Sideslope	**Upslope**	L	25	270		
	Downslope	R	-25	90		
Fall line	**Upslope**	L	30	240		
	Downslope	R	-30	70		
Trail to Fall Line Angle (°)				120		

Table 72 GCC-14 reference point distances and measuring widths

Reference Point	Distance from URP (cm) Survey #1	Survey #2	Survey #3	Survey #4	Survey #5	ML Calc
UML	60	64	62	63	67	67
UTB	80	84	82	83	87	
DTB	111	120	123	124	110	
DML	131	140	143	144	130	130
Width (cm)						
Tread	32	37	41	41	23	
% Change	---	---	30	30	-27	
ML	72	77	81	81	63	63

Table 73 GCC-15 transect point topography

Trail Name	Gap Creek Circuit		**Transect Point #**			
Topography Element	**Direction**	**Side (L/R)**	**Gradient (%)**	**Bearing (°)**	**Distance (m)**	**Grade Reversal Distance (m)**
Trail	**To End**		18	300		4
	To Start		-20	120		
Sideslope	**Upslope**	L	30	220	5	
	Downslope	R	-35	30	4	
Fall line	**Upslope**	L	33	260	5	
	Downslope	R	-45	64	5	
Trail to Fall Line Angle (°)				40		

Table 74 GCC-15 reference point distances and measuring widths

Reference Point	**Distance from URP (cm)** Survey #1	**Survey #2**	**Survey #3**	**Survey #4**	**Survey #5**	**ML Calc**
UML	70	68	69	77	85	85
UTB	90	88	89	97	105	
DTB	116	125	128	130	134	
DML	136	145	148	150	154	136
Width (cm)						
Tread	26	37	39	33	29	
% Change	---	---	52	29	13	
ML	66	77	79	73	69	51

Table 75 GCC-16 transect point topography

Trail Name	Gap Creek Circuit		Transect Point #			
Topography Element	**Direction**	**Side (L/R)**	**Gradient (%)**	**Bearing (°)**	**Distance (m)**	**Grade Reversal Distance (m)**
Trail	**To End**		-23	90		10
	To Start		20	300		6
Sideslope	**Upslope**	L	17	0	5	
	Downslope	R	-24	180	5	
Fall line	**Upslope**	L	35	330	5	
	Downslope	R	-32	170	5	
Trail to Fall Line Angle (°)				30		

Table 76 GCC-16 reference point distances and measuring widths

Reference Point	Distance from URP (cm) Survey #1	Survey #2	Survey #3	Survey #4	Survey #5	ML Calc
UML	58	67	65	55	57	67
UTB	78	87	85	75	77	
DTB	108	118	118	116	110	
DML	128	138	138	136	130	128
Width (cm)						
Tread	30	31	33	41	33	
% Change	---	---	10	37	10	
ML	70	71	73	81	73	60

Table 77 GCC-17 transect point topography

Trail Name	Gap Creek Circuit		Transect Point #			
Topography Element	**Direction**	**Side (L/R)**	**Gradient (%)**	**Bearing (°)**	**Distance (m)**	**Grade Reversal Distance (m)**
Trail	**To End**		-2	30		2
	To Start		13	220		12
Sideslope	**Upslope**	L	30	300	4	
	Downslope	R	-34	125	5	
Fall line	**Upslope**	L	30	300	5	
	Downslope	R	-35	110	5	
Trail to Fall Line Angle (°)				80		

Table 78 GCC-17 reference point distances and measuring widths

Reference Point	Distance from URP (cm) Survey #1	Survey #2	Survey #3	Survey #4	Survey #5	ML Calc
UML	47	44	46	45	49	49
UTB	67	64	66	65	69	
DTB	90	92	102	100	96	
DML	110	112	122	120	116	110
Width (cm)						
Tread	22	29	36	35	27	
% Change	---	---	63	58	22	
ML	62	69	76	75	67	61

Table 79 GCC-18 transect point topography

Trail Name	Gap Creek Circuit		**Transect Point #**			
Topography Element	**Direction**	**Side (L/R)**	**Gradient (%)**	**Bearing (°)**	**Distance (m)**	**Grade Reversal Distance (m)**
Trail	**To End**		3	20	1	1
	To Start		-3	220	2	2
Sideslope	**Upslope**	L	55	310	5	
	Downslope	R	-50	120	4	
Fall line	**Upslope**	L	55	310	5	
	Downslope	R	-50	120	4	
Trail to Fall Line Angle (°)				70		

Table 80 GCC-18 reference point distances and measuring widths

Reference Point	**Distance from URP (cm)** **Survey #1**	**Survey #2**	**Survey #3**	**Survey #4**	**Survey #5**	**ML Calc**
UML	56	51	42	47	55	56
UTB	70	71	62	67	75	
DTB	101	103	107	100	110	
DML	121	123	127	120	130	120
Width (cm)						
Tread	31	32	45	33	35	
% Change	---	---	45	6	13	
ML	66	72	85	73	75	65

Table 81 GCC-19 transect point topography

Trail Name	Gap Creek Circuit		**Transect Point #**			
Topography Element	**Direction**	**Side (L/R)**	**Gradient (%)**	**Bearing (°)**	**Distance (m)**	**Grade Reversal Distance (m)**
Trail	**To End**		-12	90		6
	To Start		2	270	2	2
Sideslope	**Upslope**	L	19	355	5	
	Downslope	R	-29	170	5	
Fall line	**Upslope**	L	19	355	5	
	Downslope	R	-29	170	5	
Trail to Fall Line Angle (°)				85		

Table 82 GCC-19 reference point distances and measuring widths

Reference Point	**Distance from URP (cm)** Survey #1	**Survey #2**	**Survey #3**	**Survey #4**	**Survey #5**	**ML Calc**
UML	27	20	21	23	20	27
UTB	47	40	41	43	40	
DTB	70	78	77	77	80	
DML	90	98	97	97	90	90
Width (cm)						
Tread	23	38	36	34	40	
% Change	---	---	56	47	73	
ML	63	78	76	74	70	63

Table 83 GCC-20 transect point topography

Trail Name	Gap Creek Circuit		Transect Point #			
Topography Element	**Direction**	**Side (L/R)**	**Gradient (%)**	**Bearing (°)**	**Distance (m)**	**Grade Reversal Distance (m)**
Trail	**To End**		-7	50	4	
	To Start		-8	210	3	
Sideslope	**Upslope**	L	22	320	5	
	Downslope	R	-26	140	4	
Fall line	**Upslope**	L	22	320	5	
	Downslope	R	-26	140	4	
Trail to Fall Line Angle (°)				90		

Table 84 GCC-20 reference point distances and measuring widths

Reference Point	Distance from URP (cm) Survey #1	Survey #2	Survey #3	Survey #4	Survey #5	ML Calc
UML	83	67	72	70	70	83
UTB	103	87	92	90	90	103
DTB	125	124	124	120	120	125
DML	139	140	144	140	140	139
Width (cm)						
Tread	23	37	32	30	30	
% Change	---	---	42	33	33	
ML	56	73	72	70	70	56

Appendix B: Survey Dates

Table 85 Dates of the five surveys for each transect point

Transect Point	Survey #1 Apr 09	Survey #2 Jun 09	Survey #3 Sep 09	Survey #4 Jan 10	Survey #5 Apr 10
1	21	2	11	27	20
2	21	2	11	27	20
3	21	2	11	27	20
4	21	2	11	27	20
5	21	2	11	27	20
6	21	2	11	27	20
7	22	2	15	27	20
8	22	2	15	27	20
9	22	2	15	27	20
10	22	3	15	27	20
11	22	3	15	28	23
12	22	3	15	28	23
13	22	3	15	28	23
14	22	3	16	28	23
15	22	3	16	28	23
16	22	3	16	28	23
17	22	3	16	28	23
18	22	3	16	28	23
19	22	3	16	28	23
20	22	3	16	28	23

Appendix C: Rainfall Data

Table 86 Total rainfall per inter-survey period and total year rainfall for each transect point

	Rainfall per Inter-Survey Period				
Transect Point	**Apr – Jun 09**	**Jun – Sep 09**	**Sep 09 – Jan 10**	**Jan – Apr 10**	**Total (mm)**
1	249	116	289	457	1,112
2	249	116	289	457	1,112
3	249	116	289	457	1,112
4	249	116	289	457	1,112
5	249	116	289	457	1,112
6	249	116	289	457	1,112
7	249	116	289	457	1,112
8	249	116	289	457	1,112
9	249	116	289	457	1,112
10	253	112	289	457	1,112
11	253	112	289	480	1,135
12	253	112	289	480	1,135
13	253	112	289	480	1,135
14	253	112	289	480	1,135
15	253	112	289	480	1,135
16	253	112	289	480	1,135
17	253	112	289	480	1,135
18	253	112	289	480	1,135
19	253	112	289	480	1,135
20	253	112	289	480	1,135

Table 87 Inter-survey days and total days for each transect point

	Days per Inter-Survey Period				
Transect Point	**Apr – Jun 09**	**Jun – Sep 09**	**Sep 09 – Jan 10**	**Jan – Apr 10**	**Total Days**
1	42	101	138	83	364
2	42	101	138	83	364
3	42	101	138	83	364
4	42	101	138	83	364
5	42	101	138	83	364
6	42	101	138	83	364
7	41	101	138	83	363
8	41	105	134	83	363
9	41	105	134	83	363
10	42	104	134	83	363
11	42	104	135	85	366
12	42	104	135	85	366
13	42	104	135	85	366
14	42	105	134	85	366
15	42	105	134	85	366
16	42	105	134	85	366
17	42	105	134	85	366
18	42	105	134	85	366
19	42	105	134	85	366
20	42	105	134	85	366

Table 88 Mean rainfall per day per inter-survey period for each transect point and mean rainfall per day per year for each transect point

	Mean Rainfall per Day per Inter-Survey Period				Mean Rainfall per Day per Year (mm)
Transect Point	**Apr – Jun 09**	**Jun – Sep 09**	**Sep 09 – Jan 10**	**Jan – Apr 10**	
1	5.9	1.2	2.1	5.5	3.1
2	5.9	1.2	2.1	5.5	3.1
3	5.9	1.2	2.1	5.5	3.1
4	5.9	1.2	2.1	5.5	3.1
5	5.9	1.2	2.1	5.5	3.1
6	5.9	1.2	2.1	5.5	3.1
7	6.1	1.2	2.1	5.5	3.1
8	6.1	1.1	2.2	5.5	3.1
9	6.1	1.1	2.2	5.5	3.1
10	6.0	1.1	2.2	5.5	3.1
11	6.0	1.1	2.1	5.6	3.1
12	6.0	1.1	2.1	5.6	3.1
13	6.0	1.1	2.1	5.6	3.1
14	6.0	1.1	2.2	5.6	3.1
15	6.0	1.1	2.2	5.6	3.1
16	6.0	1.1	2.2	5.6	3.1
17	6.0	1.1	2.2	5.6	3.1
18	6.0	1.1	2.2	5.6	3.1
19	6.0	1.1	2.2	5.6	3.1
20	6.0	1.1	2.2	5.6	3.1